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Degree: Master of Science

Year this Degree Granted: 2003

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Phosphorus Content and Accumulation of Carbon and Nitrogen in Boreal Forest Soils.

by

Audrey Véronique Lise Lanoue



A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the
requirements for the degree of Master of Science

in

Soil Science

Department of Renewable Resources

Edmonton, Alberta

Spring 2003

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled *Phosphorus Content and Accumulation of Carbon and Nitrogen in Boreal Forest Soils* submitted by *Audrey Véronique Lise Lanoue* in partial fulfillment of the requirements for the degree of *Master of Science in Soil Science*.

Pour mes parents.

ABSTRACT

Phosphorus plays a central role in energy cycling, is largely unavailable in soil and, unlike carbon and nitrogen, has low atmospheric inputs making the phosphorus capital of ecosystems largely dependent on the parent geologic material. Nitrogen accumulation requires an adequate supply of available phosphorus and both are associated in fairly definite proportions in soil organic matter. This study explores the extent that phosphorus in parent material is related to the accumulation of carbon, nitrogen and phosphorus in soil organic matter in natural soils in the Athabasca Oil Sands Region of northeastern Alberta. Forms, amounts and distribution of phosphorus in natural and reclaimed soils are compared statistically. Methods for determining available phosphorus are explored.

Nutrient accumulations in soil organic matter of natural soils are weakly related to amounts of phosphorus to 1 m and nutrient ratios indicate that the systems are not currently stressed for phosphorus. Tailings sand used in reclamation have a diminished capacity for providing available phosphorus.

ACKNOWLEDGEMENTS

Sarah Fearnley



Lee Arthur

Marvin Dudas

Clara Qualizza

Jacqueline Pollard

Marty Yarmuch

Rodi Svevistrup

Monica Molina-Ayala

Patricia Brost, Brooke Bennett, Tracy Muloin

Andrea Garton, Janet Sanders, Sabrina Mercer

Lee & Twila Barbour

Ross Huebner

Earl Anderson

Leo Paquin

Dan Binkley

Jeff Schoenau

Peiyan Qian

Synchrude Canada Ltd.

NSERC

5NR

Bill McGill & Yongsheng Feng

Len Leskiw & Phil Comeau

Kevin Devito

ACRONYMS AND ABBREVIATIONS

$h\nu$	light energy
[x]	concentration of parameter 'x'
2°	secondary material
Ae	elluviated soil pedogenic horizon
Al	aluminum
AOSR	Athabasca Oil Sands Region
ATP	adenosine triphosphate
AUD	new plot established for this study
AWHC	available water holding capacity
BD	basal diameter
BM	boreal mixedwood
Bm	slightly modified soil horizon
C	carbon
Ca	calcium
CanSIS	Canadian Soil Information System
<i>cl</i>	soil forming factor climate
C _o	organic carbon
CO ₂	carbon dioxide
CSSC	Canadian System of Soil Classification
CV	coefficient of variation
DB	Dystric Brunisol
DBH	diameter breast height
DP	direct placement
DTPA	diethylenetriamine penta-acetate
EB	Eutric Brunisol
EC	electrical conductivity
F ⁻	fluoride ion
<i>f</i>	porosity
<i>f'</i>	'function of'
Fe	iron
H ⁺	hydrogen ion
H ₂ O	water
H ₂ PO ₄ ⁻	dihydrogen phosphate
H ₂ SO ₄	sulfuric acid
HCl	hydrochloric acid
HOAc	acetic acid
HPO ₄ ²⁻	monohydrogen phosphate
IER	ion exchange resin
KCl	potassium chloride
K _m	McMurray formation, contains oil sand
KM	modified Kelowna: chemical extractant for P _a
LCC	Land Capability Classification according to LCCS
LCCS	Land Capability Classification System
LFH	Organic layers derived primarily from the accumulation of leaves, twigs and woody materials, with or without a minor component of mosses.
Ln	natural log

<i>M</i>	molar concentration ‘molar’
<i>N</i>	nitrogen
<i>N</i>	normal concentration ‘normal’
<i>n</i>	sample size
<i>N</i> ₂	nitrogen gas
<i>N</i> _a	available nitrogen
NaHCO ₃	sodium bicarbonate
NH ₄ ⁺	ammonium ion
NH ₄ F	ammonium fluoride
NH ₄ OAc	ammonium acetate
<i>N</i> _o	organic nitrogen. Since inorganic nitrogen is only a small component of <i>N</i> _t , <i>N</i> _t is used as an equivalent to <i>N</i> _o
NO ₃ ⁻	nitrate ion
<i>O</i>	oxygen
<i>o</i>	soil forming factor organisms
OB	overburden
OGL	Orthic Gray Luvisol
OH ⁻	hydroxide ion
OM	organic matter
OM%	percent organic matter (g 100 ⁻¹)
<i>P</i>	phosphorus
<i>p</i>	soil forming factor parent material (PGM)
<i>P</i>	statistical <i>P</i> -value
<i>P</i> _a	available phosphorus
<i>P</i> _f	Pleistocene-fluvial
<i>P</i> _g	Pleistocene-undifferentiated till
PGM	parent material, parent geologic material
pH	-log[H ⁺] Generally referring to water extracts, but can refer to CaCl ₂ or saturated paste extracts.
<i>P</i> _i	inorganic P
<i>P</i> _l	Pleistocene-lacustrine
<i>P</i> _o	organic P
PO ₄	phosphate
PO ₄ ³⁻	trivalent phosphate ion
PSP	Alberta Pacific permanent sample plot
<i>P</i> _t	total phosphorus
<i>r</i>	soil forming factor topography
<i>S</i>	sulfur
SCWG	Soil Classification Working Group

SGL	Solonetzic Gray Luvisol
SOM	soil organic matter
SV	soil/vegetation plot
t	soil forming factor time
TS	top soil
TSS	tailings sand
US	upper subsoil
w	Shapiro-Wilk statistic
α	alpha, error rate
θ	volumetric water content

TABLE OF CONTENTS

Chapter 1:	Introduction.....	1
1.1	Introduction	1
1.2	Goals and Objectives.....	1
Chapter 2:	Indices for assessing available phosphorus in forest soils.....	3
2.1	Introduction	3
2.2	Background	3
2.2.1	Phosphorus.....	3
2.2.2	Mechanisms for determination of easily extractable bioavailable P	6
2.2.3	Conventional extractants and pH	7
2.2.4	Ion exchange resin.....	7
2.3	Objectives	8
2.4	Methods.....	8
2.4.1	Study Area.....	8
2.4.2	In-situ IER bags.....	10
2.4.3	Extractants and Extraction Procedures.....	10
2.4.4	Statistical analysis.....	10
2.5	Results.....	12
2.5.1	Coefficients of variation.....	12
2.5.2	Correlations of soil test methods for P_a versus IER	12
2.6	Discussion and conclusion.....	16
2.6.1	IER and soil test methods.....	16
2.6.2	Soil test methods for determination of P_a	17
2.7	Literature Cited	18
Chapter 3:	Total P content and accumulation of C and N in Boreal forest soils	21
3.1	Introduction	21
3.2	Background	21
3.2.1	Ecological succession	21
3.2.2	Succession and pedogenesis	22
3.2.3	P control of accumulation of soil organic matter	23
3.2.4	P transformations and availability during pedogenesis	25
3.3	Objective.....	28
3.4	Study area.....	28
3.4.1	Climate.....	28
3.4.2	Soils.....	28
3.4.3	Vegetation.....	28
3.5	Methods.....	28
3.5.1	Site selection	28
3.5.2	Soil sample collection and preparation	29
3.6	Results.....	31
3.6.1	Total C, N and P.....	31
3.6.2	Nutrient ratios.....	32
3.6.3	Linear regression	32
3.7	Discussion	34
3.7.1	Relationships between P_i and accumulated C_o , N and P_o	34
3.7.2	Relationships between C_o , N and P_o in OM of LFH and shallow mineral soil	36
3.8	Conclusion.....	37

3.9 Literature Cited	37
Chapter 4: Forms, amounts and distribution of C, N and P in natural and reclaimed soils of the Athabasca Oil Sands Region	41
4.1 Introduction	41
4.2 Objectives	42
4.3 Background	42
4.3.1 Study area	42
4.3.2 Oil sand mining	44
4.4 Methods	51
4.4.1 Statistical design and analysis	51
4.4.2 Site selection	53
4.4.3 Plot establishment	54
4.4.4 Sample and data collection	54
4.5 Results	55
4.5.1 Soil and vegetation classification	55
4.5.2 Soil physical and chemical properties	59
4.5.3 Form and amounts of C, N and P to 1 m and 0.2 m depths	62
4.5.4 Phosphorus distribution with depth	69
4.6 Summary and conclusion	73
4.6.1 Forms and amounts of C, N and P in natural and reclaimed soils	73
4.6.2 Distribution of P in natural and reclaimed soils	74
4.7 Discussion	75
4.7.1 P availability in natural soils	75
4.7.2 Implications for sand reclamation	79
4.8 Conclusion	80
4.9 Literature cited	81
Chapter 5: Synthesis	84
5.1 Summary	84
5.1.1 Natural soils	84
5.1.2 P content and accumulation of C and N	84
5.1.3 P availability	84
5.2 Reclaimed soils	85
5.2.1 Fine textured reclamation prescriptions	85
5.2.2 Coarse textured reclamation prescriptions	85
5.3 Recommendation	86
5.3.1 Appropriate comparisons	86
5.3.2 Operational considerations	86
5.4 Future research	87
5.4.1 Biogeochemical cycling	87
5.4.2 Soil development	87
5.5 Concluding statement	87
Appendix A: Projects and monitoring programs for which plots are linked	88
Appendix B: Preparation of ion exchange resin (IER) bags for in-situ determination of available P and N	89
Appendix C: Soil chemical data	93
Appendix D: Soil profile descriptions	110
Appendix E: Vegetation data	155

LIST OF TABLES

Table 2-1. CV (%) results for Olsen, Bray, KM, and IER P _a indices for 45 samples.....	12
Table 2-2. R ² -values and dissimilarity coefficients comparing three extraction methods.....	14
Table 2-3. Comparison of the IER and soil test methods for the determination of available nutrients.....	16
Table 3-1. Characteristics of proposed soil developmental stages (extended from Vitousek and White 1981).....	27
Table 3-2. Mean total amounts of forms of C, N and P for fine and coarse textured soils in northeastern Alberta [†]	31
Table 3-3. Mean nutrients ratios for fine and coarse textures soils in northeastern Alberta.	32
Table 3-4. R ² -values for regression analyses of various relationships in fine and coarse textured soils of northeastern Alberta.	33
Table 4-1. Alberta Soils Advisory Committee requirements for top-soil (0-20cm) amendments for reclaimed soils in the Athabasca Oil Sand Region (Macyk et al. 1987).	46
Table 4-2. Extent of reclaimed soil prescriptions at the Syncrude Mildred Lake mine and the Suncor mine in 1997 (Leskiw and Moskal 1997a,b).	50
Table 4-3. Fertilizer inputs to reclamation prescriptions.	50
Table 4-4. Selected pre-planned comparisons between treatments.	52
Table 4-5. Site locations, soil and vegetation classifications for natural sites.	57
Table 4-6. Site locations, soil classification and tree species for reclaimed sites.....	58
Table 4-7. TEC, CEC and pH of surface soil and EC of C horizon of natural sites.	59
Table 4-8. Select mean physical and chemical properties of reclaimed sites by horizon.	61
Table 4-9. Mean amounts of N, P and C to 1 m and 0.2 m depths by treatment group with standard error of the mean.....	63

LIST OF FIGURES

Figure 2-1. Flow diagram of organic and inorganic phosphorus forms (adapted from Hmeidan 1982).....	4
Figure 2-2. Concentrations of species of phosphate ions as a function of pH (after Brady and Weil 1996).....	5
Figure 2-3. Plot design.	9
Figure 2-4. IER correlations with soil test results	13
Figure 2-5. Spearman's rank correlations for the three extraction methods.	14
Figure 2-6. Dissimilarity plots for the three extraction methods according to pH class.	15
Figure 3-1. Schematic diagram illustrating the coupling between vegetation (ecological succession) and soils (pedogenesis).	22
Figure 3-2. Primary successional P transformation model after Walker and Syers (1976) and theoretical N ₂ -fixation rate model after Gorham (1981).	26
Figure 3-3. Study sites and surficial geology of the AOSR (map from Spiers 1989).	30
Figure 4-1. Location of study area relative to the lower Cretaceous oil sand formations in Alberta, Canada (base map adapted from Jardine 1974; Nyren and Mittal 1979; Conoco Inc. 2002).	43
Figure 4-2. Regional stratigraphic column of the Mesozoic and Cenozoic eras (adapted from BOVAR 1996).	44
Figure 4-3. Schematic representation of the mining and material salvage process with respect to materials requiring capping (OB and TSS) and materials available for reclamation (peat [H ₀], till [2°] and a mixture of peat and till [DP]) considered in this study.	48
Figure 4-4. Reclamation prescriptions investigated.	49
Figure 4-5. Experiment design structure (symbols defined in Figure 4-3).	51
Figure 4-6. Soil textural class (according to the CSSC) of natural soil PGMs and reclamation materials (Textural triangle adapted from SCWG 1998).	60
Figure 4-7. Mean total P content of treatments to 1 m depth, fertilizer contributions and proportions held in the LFH and top 0.2 m of profiles.	64
Figure 4-8. Mean total N of treatments to 1 m depth, fertilizer contributions and proportions held in the LFH and 0.2 m of profiles.	65
Figure 4-9. Mean P ₀ content of treatments to 1 m depth and proportions held in the LFH and 0.2m of profiles.	66
Figure 4-10. Mean P _a and N _a content of treatments and proportions held in the LFH and 0.2 m of profiles.	67
Figure 4-11. Stacked bar graph of mean C ₀ , and C _i , adding to C _i by prescription and proportions of C ₀ held in the LFH and 0.2 m of profiles.	69
Figure 4-12. Stacked bar graphs of P profiles for natural coarse textured natural sites.	70
Figure 4-13. Stacked bar graphs of P profiles for natural fine textured natural sites.	71
Figure 4-14. Stacked bar graphs for mean P profiles for reclaimed sites.	73
Figure 4-15. P as a function of two particles size fractions (2000 - 53 µm and < 53 µm) for the B and C horizons of natural sites.	76
Figure 4-16. pH (H ₂ O) profiles for all sites in study according to treatment.	78

CHAPTER 1: INTRODUCTION

1.1 Introduction

In the Athabasca Oil Sands Region (AOSR) of northeastern Alberta, oil sands mining and forestry exert pressure on boreal forest ecosystems. Forestry has been limited to natural ecosystems that can be susceptible to degradation if not properly managed. Oil sands mining, on the other hand results in complete disruption of natural ecosystems and ecosystems must be reconstructed on a landscape scale. The added pressure of harvesting on these reconstructed ecosystems leads us to pose additional questions about their long-term sustainability.

The goal of reclamation in the AOSR is to develop strategies that will lead to self-sustaining ecosystems. Predicting sustainability of ecosystems entails predicting their trajectories over time, which is complex due to the plethora of ecosystem components and their interactions. This difficulty can be overcome by using a functional systems approach to examine key factors influencing the accumulation and cycling of major elements, specifically carbon (C), nitrogen (N), and phosphorous (P), of water, and energy in these ecosystems. A functional approach to ecosystem dynamics is hierarchical and systematic, provides tests of key outcomes, and allows predictions of ecosystem trajectories. The key functions influencing quantities and availability of elements in forest ecosystems are: additions, removals, transformations and translocations. Reclamation of disturbed sites with the goal of long-term sustainability requires that the element cycles of target ecosystems are understood, that the element capital and distribution within starting materials are known, and that the potential changes in element capital, distribution and cycling during stand development are understood. Ecosystem development on reconstructed sites will fail if nutrient capital and circulation rates are not compatible with the requirements of target ecosystems.

1.2 Goals and Objectives

The present study involved a combination of field data collection to quantify carbon, nitrogen, and phosphorus in selected natural and reclaimed soils in the AOSR and statistical analysis with the goals:

- to examine the relation of phosphorus to the accumulation of carbon and nitrogen in natural soils,
- to quantify and compare soil and litter nutrients in selected natural and reclaimed ecosystems in the Athabasca Oil Sands Region, and

- to use collected data to evaluate potential options for restoring and maintaining sustainable forest ecosystems on land reclaimed following oil sands mining.

Results associated with specific objectives associated with these goals are recorded in each of three data chapters with objectives:

- to compare indices for assessing available phosphorus (P_a) in forest soils (Chapter 2),
- to relate total P to accumulation of C and N in boreal forest soils (Chapter 3), and
- to compare the forms and distribution of P, C and N between fine and coarse parent materials, between natural and reclaimed ecosystems, and between reclamation prescriptions (Chapter 4).

These results and associated conclusions are combined in a synthesis arguing that P_a does not restrict nitrogen fixation and development of element cycles under natural conditions in the AOSR, that reclamation strategies based on fine textured overburden and potentially natural sands are also not likely to restrict element cycles but that tailings sand is not an appropriate surrogate for natural sands (Chapter 5).

CHAPTER 2: INDICES FOR ASSESSING AVAILABLE PHOSPHORUS IN FOREST SOILS.

2.1 Introduction

The determination of the availability or bioavailability of nutrients is critical to understanding nutrient cycling in ecosystems. The two most often limiting nutrients in forest ecosystems are nitrogen (N) and phosphorus (P) (Kimmins 1997; Fisher and Binkley 2000). The purpose of the determination of available P (P_a) is to measure a *pool*[†] of soil P that is in some way related to the portion of soil P which is plant available (Tiessen and Moir 1993). As such, P_a is a functional concept rather than a single entity. The determination of the amount of a nutrient that is actually available to a plant is determined by soil factors and plant factors: specifically the soil's ability to provide the nutrient and the plant's ability to utilize the nutrient once supplied (Corey and Schulte 1973).

Chemical extractants are conventionally used to determine P_a in soil samples. Relationships between the extraction results and actual plant uptake, growth or yield are established over many years of experiments testing plant responses to fertilization with regression analysis (Tiessen and Moir 1993) as a method for linking the plant and soil factors. Still, these procedures are limited in that they are merely a static measure of a P pool, are operationally defined and pH dependent, the latter making it exceedingly difficult to interpret data for which a wide pH range exists. This chapter presents results from a comparison of three conventional extractants methods and in-situ ion exchange resin (IER) bags with the objective to select the most suitable method across the soil sample pH range. Soil samples from surface horizons of natural and reclaimed soils in the Athabasca Oil Sands Region (AOSR) of varying soil texture, organic matter content and pH were used.

2.2 Background

2.2.1 Phosphorus

P is only a minor constituent of soil, ranging from 0.02 to 0.5% with an average of 0.05% (Lindsay et al. 1989). Total P (P_t) in soil can be grouped into two distinct pools: organic P (P_o) and inorganic P (P_i) with various forms within these two pools with a variety of transformations between forms (Figure 2-1).

[†] Identifies diverse constituents that contain P and share a common property, such as solubility in a specified solvent, organic character, dissolution or exchange rate, etc.

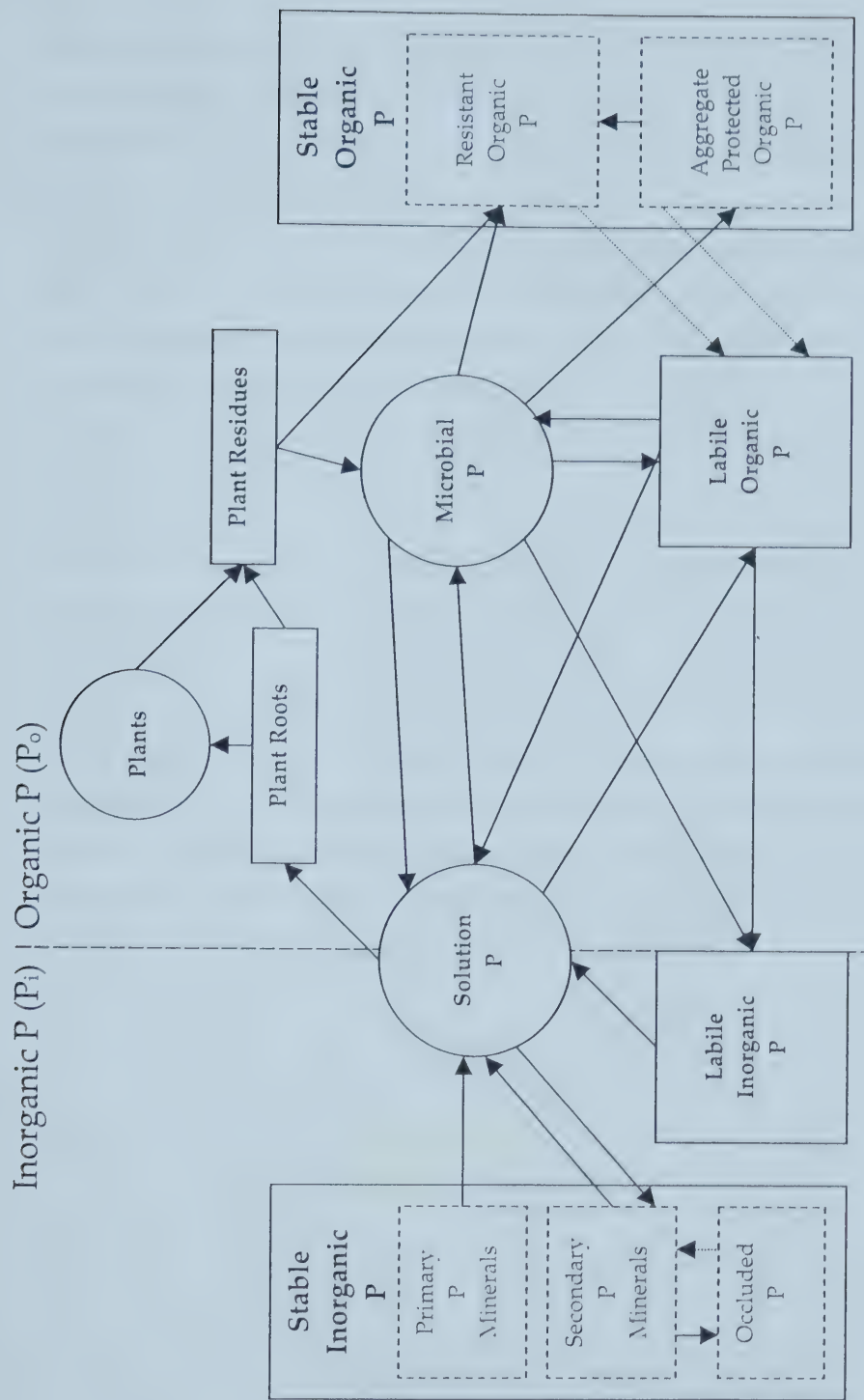


Figure 2-1. Flow diagram of organic and inorganic phosphorus forms (adapted from Hmeidan 1982).

Most of the P (95-99%) in soil is in stable organic and inorganic forms and is thus largely unavailable to plants. Only small amounts are present in plant available forms in equilibrium with the soil solution, the concentration of which is controlled by the solubility of phosphate bearing minerals present (Hayman 1975).

Primary minerals are formed from igneous or metamorphic rocks and secondary minerals are either inherited from sedimentary rocks or formed in soils by weathering (Schulze 1989). Apatite is the dominant phosphate bearing mineral accounting for greater than 95% of the total P in igneous rocks (Lindsay et al. 1989). Grains of apatite have been found in both sand and silt fractions of a number of soils (Lindsay et al. 1989). Syers et al. (1967) reported apatite inclusions in quartz minerals.

2.2.1.1 Available P

Apatite weathering occurs over geologic time scales, and appears to be controlled by temperature and surface area of the minerals (Guidry and Mackenzie 2000). In the presence of mycorrhizal *Pinus sylvestris* (L.) roots, estimates of apatite dissolution over 210 days in the greenhouse range from 0.1 to 0.3% based on Sr uptake data and from 0.3 to 0.9% based on P uptake data (Wallander 2000). Phosphorus dissolved from apatite enters the soil environment as the trivalent (PO_4^{3-}) phosphate ion. Once in soil solution, the phosphate ion tends to combine with (H^+) hydrogen ions to form monohydrogen (HPO_4^{2-}) or dihydrogen (H_2PO_4^-) phosphate, the former dominating the soil solution at pH 9 and the latter dominating under acid soil conditions and being the dominant form for plant uptake (Figure 2-2; Brady and Weil 1996).

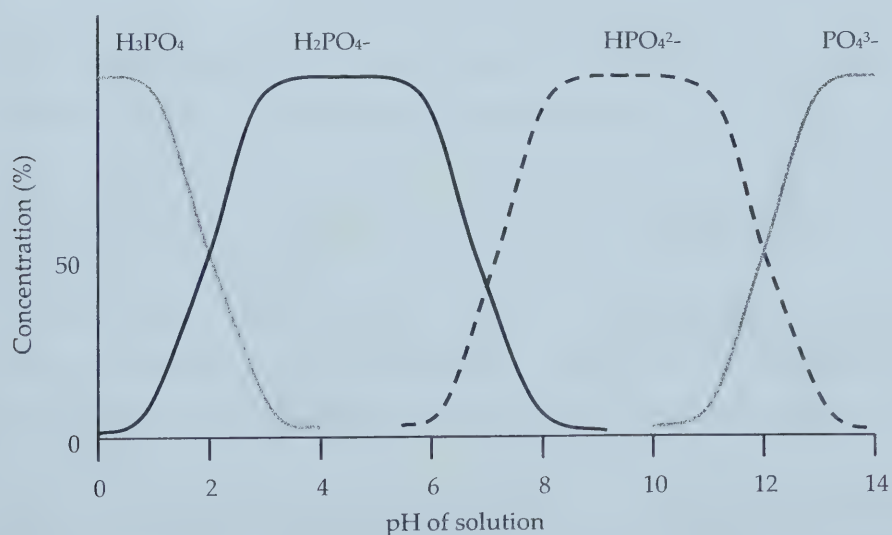


Figure 2-2. Concentrations of species of phosphate ions as a function of pH (after Brady and Weil 1996).

Under low soil pH conditions (<5.5), aluminum and iron are relatively soluble and form highly stable, insoluble aluminum and iron phosphates with H_2PO_4^- . Under high soil pH (> 7) conditions soluble calcium is plentiful and limits P availability by forming slightly soluble precipitates with the HPO_4^{2-} (Hausenbuiller 1985).

These secondary phosphate minerals can account for significant amounts (>70% of total P in soil) of P. Norrish (1968) found secondary phosphate minerals to be concentrated in the silt and clay fractions of highly weathered Australian soils.

2.2.1.2 Organic P

Over time, P_i is transformed to P_o and P_o accumulates in soil, particularly at the soil surface (Walker and Adams 1958). Although it has been demonstrated that plants can take up P from P_o sources, P_i is primarily responsible for the P nutrition of plants (Dalal 1977). More importantly, P_o accumulated in organic matter can indirectly contribute considerably to the P nutrition of plants once mineralized to P_i . The total organic carbon: P_o ratio ($\text{C}_o:\text{P}_o$) has been used by some to predict net immobilization and mineralization in soils (see Dalal 1977). It has been proposed that if the $\text{C}_o:\text{P}_o$ ratio is 200:1 or less mineralization is likely to occur and if the $\text{C}_o:\text{P}_o$ ratio is 300:1 or greater, immobilization is likely to occur (Alexander 1977). This index for predicting immobilization or mineralization of P is not widely accepted because P_i is often present in organic materials making the index inconsistent (Dalal 1977).

2.2.2 Mechanisms for determination of easily extractable bioavailable P

Chemical extractants have developed (for a review see Fixen and Grove 1990) for the determination of P_a based on one or more of the four basic reactions by which P is removed from the soil: 1) solvent action of acids, 2) anion replacement, 3) complexing of cations binding P, and 4) hydrolysis of cations binding P (Kamprath and Watson 1980):

Solvent action of acids: The acids provide sufficient H^+ activity to dissolve acid soluble phosphates including (in order of their acid solubility) calcium phosphates, aluminum phosphates and iron phosphates.

Anion replacement: Organic anions such as acetate and citrate and some inorganic anions such as fluoride (F^-) (Bray and Kurtz 1945) can effectively replace P adsorbed on the surfaces of calcium carbonate and hydrated aluminum and iron oxides preventing the re-adsorption of P in acid solutions.

Complexing of cations binding P: Fluoride ions (F^-) are commonly used and effective for the complexing with aluminum, thereby releasing P from aluminum phosphates. F^- also precipitates

with calcium, thereby releasing P bound in calcium phosphates. Organic acids, such as acetate and citrate, also complex aluminum ions.

Hydrolysis of cations binding P: Solutions containing OH^- ions hydrolyze aluminum and iron thereby releasing P from aluminum and iron phosphates. Sodium bicarbonate (NaHCO_3) is a common and effective solution for the extraction of aluminum and iron phosphate bound P (Kamprath and Watson 1980) since the bicarbonate ion rapidly hydrolyzes in water according to Equation 2-1 (Bray and Weil 1996).



2.2.3 Conventional extractants and pH

Based on these chemical reactions, it is clear that the suitability of an extractant for the determination of P_a depends on the pH, or more specifically, the buffering capacity of soil. Acidic extractants are not appropriate for use with soils having higher than neutral pH because the acid is neutralized resulting in underestimation of P_a compared to non-acidic extractions. The Olsen (sodium bicarbonate) extractant is recommended for neutral to calcareous soils (Olsen et al. 1954), and Bray-type (hydrochloric/hydrofluoric acid) extractants for acidic soils (Kalra and Maynard 1991). The practical result is that data obtained across a group of samples spanning a range in pH are difficult to interpret because the applicability of the method comes into question. Qian et al. (1994) proposed the Modified-Kelowna (KM) extractant as a suitable extract for use across a range of soil pH. It is similar to the Bray-type extractants in that dilute ammonium fluoride is used to compete with P to displace adsorbed-P (Bray and Kurtz 1945). The KM solution is acidified by a concentrated solution of a weak acid (acetic acid) instead of a weak solution of a strong acid (such as hydrochloric acid in the Bray solutions) (Ashworth and Mrazek 1989). The 0.25 N acetic acid maintained the extraction pH effectively on soils with up to 38% calcium carbonate (CaCO_3) and extracted P results were strongly correlated to reference P results obtained using Bray-I for $\text{pH} < 7$ and Olsen for $\text{pH} > 7$ (van Lierop 1988).

Although chemical extractants are widely used, their modes of action and selectivity are not fully understood and are limited to determining indices of P_a because they are operationally defined, only measure static P pools (Cooperband and Logan 1994), and are dependent on soil pH.

2.2.4 Ion exchange resin

Anion exchange resins were introduced by Amer et al. (1955) as an improvement over the chemical soil test methods for the determination of P_a and they proposed that ion exchange resin function in a manner analogous to plant roots. Resin was freely suspended with water and soil

(crushed to pass a 150µm sieve) during extraction. Filtering was required to separate the resin from soil prior to analysis. This procedure was plagued with low P results due to loss of resin during filtration until Sibbesen (1977) proposed that resin be contained in nylon netting. Since then, ion exchange resins have been used in the establishment of the Phytoavailability Soil Test where a mixed-bed ion-exchange capsule is embedded in saturated paste soil samples as an innovative method for determining plant available nutrients affected by diffusion (Yang et al. 1991), an important aspect of nutrient availability not taken into account by chemical extraction methods or by the freely suspended resin bead method.

In 1983, Binkley and Matson published a study of forest soil N availability under field and greenhouse conditions where ion exchange resin (IER) bags after Sibbesen (1977) were buried in the field (in-situ). They concluded that the field resin method was likely sensitive to on-site conditions not detectable by the conventional soil extraction methods. Because the IER approach is more analogous to plant root function than the chemical extractants, and because IER anion exchange is not pH dependent, the IER method is likely to return P_a results more representative of what was actually available to plants during the incubation period as distinct from what is potentially extractable from the soil and thereby may act as the benchmark to which the extractant method performance can be compared.

2.3 Objectives

The objectives of this study were: 1) to explore variation in extractable P content over a wide soil pH range measured by the Olsen, Bray-1 and Modified-Kelowna extractants; 2) to explore the relationship between these extractants and in-situ IER bags; and 3) to select an extraction method for the comparison of natural and reclaimed soils with widely varying soil pH. A group of surface soils of natural and reclaimed ecosystems in the AOSR with substantial pH differences, organic matter contents and dominant texture of mineral component were used.

2.4 Methods

2.4.1 Study Area

In May of 2001, 45 transects (40 m long) were established in natural and reclaimed ecosystems in the AOSR in northeastern Alberta, ranging between 56° and 59°N latitude and 113° and 110°W longitude. Of the total 45 sites, 20 were natural ecosystems, 10 dominated by fine textured parent material and 10 dominated by coarse textured parent material. Along each transect, a resin bag was buried at 0, 10, 30 and 40 m and one soil investigation pit was dug at 20 m (Figure 2-3). Resin bags were buried at the organic-mineral interface to a maximum depth of 15 cm. One

composite soil sample was collected for each transect. For a map of the location of each site see Chapter 3, Figure 3-3.

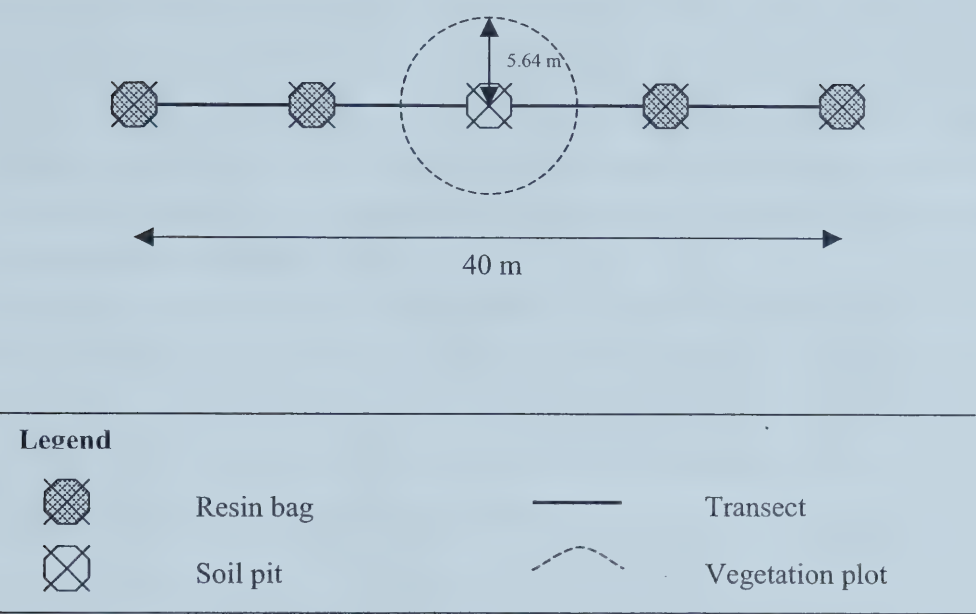


Figure 2-3. Plot design.

Reclaimed sites ($n=25$) were located at the Syncrude Canada Ltd. Mildred Lake mine (approximately 35 km North of Fort McMurray) and at the Suncor mine (approximately 20 km north of Fort McMurray) for a total of four different conventional reclamation soil prescriptions. Undisturbed sites ($n=20$) were selected from a network of monitoring and research plots established in the region (Appendix A) extending north to the 22 km post on the Fort Chipewean winter road and south to near the Highway 63 intersection of the Hangingstone River.

2.4.1.1 Soils

A total of 45 composite soil samples (TS COMP samples, Appendix C) were collected from undisturbed and reclaimed soils using a 6 cm core straddling the depth at which the IER bags were buried. Soils ranged in pH (H_2O , 2:1) from 4.41 to 8.05, electrical conductivities (EC) were all less than 1.2 dS/m, total carbon ranged from 12.5 to 280.7 g kg⁻¹, and bulk density ranged from 0.05 to 1.51 Mg m⁻³. Undisturbed site LFH thicknesses ranged from 5 to 25 cm with a mean of 9.9 cm. The reclaimed sites had peat/mineral mix surface horizons ranging from 0 to 73 cm with a mean of 17 cm. Organic material consisted of undisturbed LFH in natural sites or peat in the reclaimed soils. Texture of underlying mineral horizons ranged from loamy sands to clays.

2.4.2 In-situ IER bags

IER bags were prepared as established by Sibbesen (1977) using 17 grams of moist weight mixed bed IONAC® NM-60, H⁺/OH⁻ saturated resin beads according to Binkley and Matson (1983), only slightly modified in that the ends of the stockings were tied in knots rather than stapled. IER bags were buried along transects as described above and incubated for 78 days during the summer field season of 2001. At the end of the incubation, bags were removed from soil, stored in individual plastic bags and kept cool until they were extracted using 100 ml 2M KCl with agitation (D. Binkley, personal communication, Colorado State University, Fort Collins, Colorado; Appendix B), filtered and analyzed for PO₄-P using a Technicon TM Autoanalyzer II automated colorimetry system (Technicon 1973).

Ten blanks were extracted and analyzed to check for P contamination in the resin. Five 17.0 g samples of resin were weighed out and extracted and five resin bags were cut open, resin removed and extracted according to the method described above. Virtually no PO₄-P was detected in the blanks (results all below detection limit of 0.0024 ppm in solution).

2.4.3 Extractants and Extraction Procedures

P_a extractions were performed using the standard procedures outlined for the Olsen (Olsen et al. 1954), Bray-I (Bray and Kurtz 1945) and KM (Ashworth and Mrazek 1995) extractions. Very briefly, these methods consist of weighing out a mass of air-dried, <2 mm soil sample and extracting, with agitation, with 0.5M NaHCO₃ for Olsen, 0.03M NH₄F & 0.025M HCl for Bray-I and 0.015M NH₄F, 1.0M NH₄OAc & 0.5M HOAc for KM at a 10:1 extractant to soil ratio. Subsequent to extraction, samples are filtered through quantitative filter paper (Whatman 42 equivalent) and the soil extract analyzed for P-PO₄ colorimetrically by the ascorbic molybdenum blue complex (Murphy and Riley 1962) according to the Technicon method (1973) for Bray and KM and Olsen with flow injection analysis (B. Vaughan, personal communication, MDS Harris Soil Testing Laboratory, Lincoln, Nebraska; Lachat 2001).

2.4.4 Statistical analysis

Results from the extractions were compared using three statistical analysis tools: coefficient of variation (CV), Spearman's rank correlation and dissimilarity coefficients and plots.

Coefficient of variation (CV): CV is the standard deviation (s) divided by the mean ($\bar{X}$) multiplied by 100 percent (Equation 2-3).

Equation 2-2.

$$CV(\%) = \frac{s}{\bar{X}}(100 \text{ percent})$$

The standard deviation is a measure of dispersion in the data. Therefore, the greater the standard deviation, the greater the variability in the samples. The CV (%) therefore normalizes the dispersion to the mean of the samples. The larger the CV (%), the greater the proportional dispersion among the samples, the smaller the CV (%), the smaller the dispersion among the individual samples from the population.

For this analysis, the CV (%) will be used as a measure of the sensitivity of each method to detect differences among the samples, given that the samples are constant across the methods. Thus, the higher the CV (%), the more sensitive the method is to differences among samples and the lower the CV (%), the less sensitive the method is to the differences among samples.

Spearman's rank correlation: Correlation is performed on rankings assigned to each sample based on the results obtained by each method (Zuwaylif 1979). This is achieved by sorting the results in ascending order and assigning a rank of 1 to n for each of the methods used.

Consequently, the data are transformed from concentrations to ranks upon which the correlation is performed. Correlations were performed in SAS (1999) using the **Proc corr** function. The benefit of using Spearman's rank correlation is that the analysis is performed on the rank rather than the raw data. Given that different methods are being compared, differences in the absolute values of P are expected, but the relative value of P is paramount.

Dissimilarity coefficients and plots: Dissimilarity coefficients are an extension of Spearman's rankings, calculated by Equation 2-3. If one imagines that all methods were identical (that is, they returned identical rankings of the samples), the mean difference in rank among the methods (and the dissimilarity coefficient) would be zero.

Equation 2-3.

$$d = \frac{\sum (R_1 - R_2)^2}{n}$$

Where: d = dissimilarity coefficient

R_1 = rank from method 1

R_2 = rank from method 2

n = sample size

The higher the dissimilarity coefficient between two methods, the more dissimilar the methods are (in terms of rank) and the smaller the dissimilarity coefficient between two methods the more similar the methods are (in terms of rank).

Comparing the three extraction methods at once creates a triangle, the center of which is taken as the best estimate of the true ranking (as the mean of all estimates). Using the dissimilarity

coefficients for each method, the mean dissimilarity coefficient can be calculated. The dissimilarity coefficient of each method with respect to the mean indicates how close or far the individual method is from the mean. The method with the smallest distance from the mean would be preferred for ranking the samples. The population of dissimilarity coefficients are tested using a simple analysis of variance to determine if the difference is significant.

2.5 Results

2.5.1 Coefficients of variation

Coefficients of variation are presented in Table 2-1 for each of the three extraction methods and for the IER bags. Of the extraction methods, the Olsen method returns the lowest CV (%) in both pH classes and across all samples while the KM method returns the highest CV (%) in both pH classes and across all samples. This suggests that of the extraction methods, the Olsen is the least sensitive to differences among the samples and the KM is the most sensitive to differences among the samples. The CV (%) results suggest that the KM method would be the most desirable extraction method to use due to its greater ability to discriminate among sites. The IER CV (%) values are much higher than any of the extraction methods in both pH classes and across all samples which supports the proposition that this in-situ method is sensitive to on-site variables that extraction methods do not detect, or which are removed by the extraction process.

Table 2-1. CV (%) results for Olsen, Bray, KM, and IER P_a indices for 45 samples.

pH Group	Soil-test methods			IER
	Bray	KM	Olsen	
pH < 6	51.1	57.9	42.2	86.7
pH > 6	96.5	109.3	87.6	155.0
All samples	79.5	85.2	65.8	135.0

2.5.2 Correlations of soil test methods for P_a versus IER

Correlations on raw data are presented in Figure 2-4. It is apparent that no relationship exists between IER and the soil test results of Bray, Olsen or KM. The R²-values for correlations illustrate in Figure 2-4 are <0.01 (Figure 2-4).

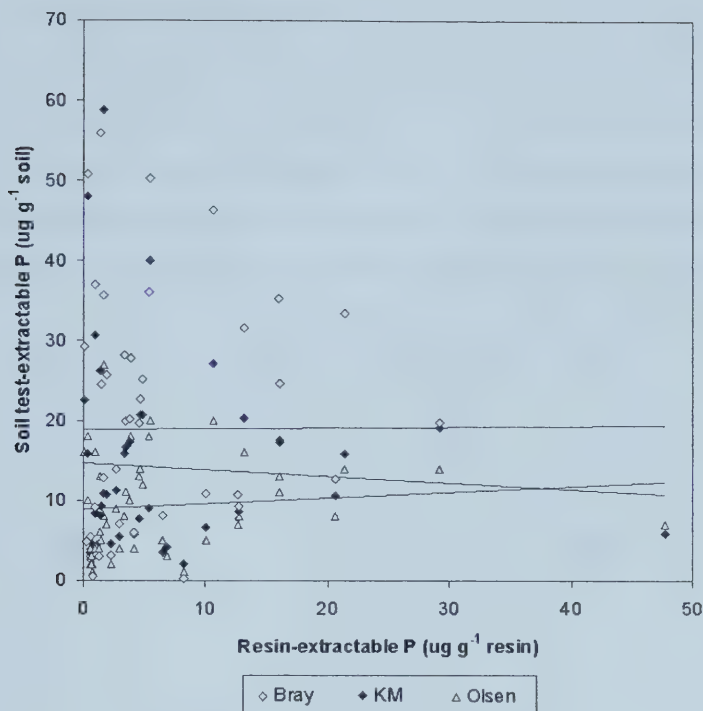


Figure 2-4. IER correlations with soil test results

Improvement in correlations were attempted by adjusting the soil test results for moisture content at time of sampling (θ), organic matter percentage (OM%), total organic carbon (C_o), total carbon (C_t), porosity (f) and/or pH using the following base formula:

Equation 2-4.
$$[\text{soil test result } (\mu\text{g} / \text{g})]_{\text{adjusted}} = \left(\frac{\theta^{10/3}}{f^2} \right) \left(\frac{x}{\alpha} \right)$$

Where:

θ = volumetric water content

f = porosity

x = original soil test result ($\mu\text{g} / \text{g}$)

α = adjustment: $\alpha_a = (\text{pH} - 7)^2$; $\alpha_b = C_t (\mu\text{g} / \text{g})$; $\alpha_c = C_o (\mu\text{g} / \text{g})$; $\alpha_d = \text{OM}\%$; $\alpha_{ab} = (C_t (\text{pH} - 7)^2)$; $\alpha_{ac} = (C_o (\text{pH} - 7)^2)$; $\alpha_{ad} = (\text{OM}\% (\text{pH} - 7)^2)$.

The first half of the adjustment is after Millington (in Hillel 1982) to account for diffusion because it is the dominant process controlling P movement in soil. The second half adjusts for pH and organic matter content, both of which have been found to be strongly related to P availability in soils (Dalal 1977). Adjustments yielded no significant improvements in correlation so correlations are presented without any adjustments.

The correlation between the soil test methods for P_a and in-situ IER bags is non-existent, so the IER results cannot be used as a benchmark to which the soil test methods can be compared, as was intended. The best soil test method for use in ranking the sites must be determined through comparisons among the methods themselves. Results of correlations and comparisons among each of the three methods are presented in Table 2-2 and Figure 2-5.

Table 2-2. R²-values and dissimilarity coefficients comparing three extraction methods.

Regression	R ²		Dissimilarity coefficient		
	Standard	Spearman's	pH < 6	pH > 6	All
Bray vs. KM	0.64	0.80	0.82	0.74	0.67
KM vs. Olsen	0.71	0.83	0.59	0.40	0.54
Bray vs. Olsen	0.75	0.80	0.80	0.66	0.82

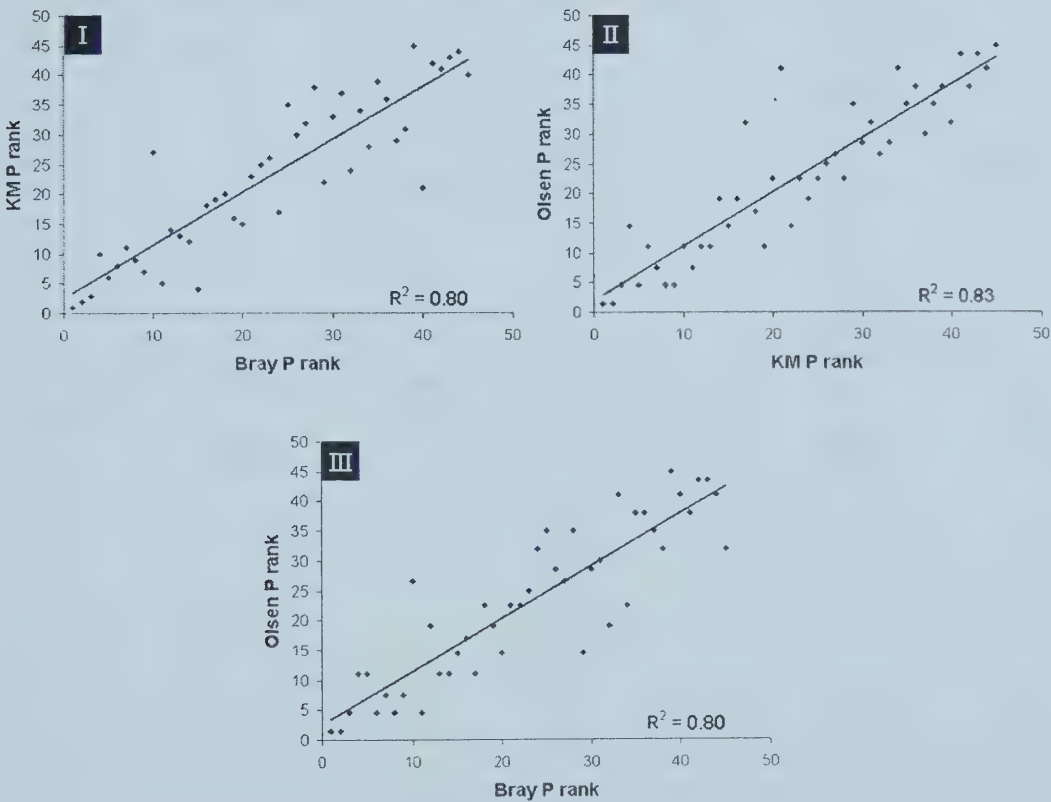


Figure 2-5. Spearman’s rank correlations for the three extraction methods.

All three extraction methods return similar ranks, the KM method having only slightly better correlation with Bray and Olsen (Figure 2-5: I and II) than Bray and Olsen have with each other (Figure 2-5: III) suggesting that the KM method may provide a soil P_a ranking most consistent

with the true ranking of which our best estimate is the mean of the estimates returned by the three extraction methods.

Because all methods return rankings that are equally correlated to each other, it is impossible to select one single most accurate method. But, if given our confidence in each method individually, the mean of the three methods provides the best estimate of the true value. Based on the proposition that the mean of the three soil test methods is the best indicator of the true ranking, dissimilarity plots were generated (Figure 2-6). When the soil pH is less than 6, the Olsen method is the most similar to the mean (lowest dissimilarity coefficient from the mean) followed by the Bray and KM methods. This is contrary to what was expected based on the chemistry of the Bray and KM extractants which should perform better than the Olsen on this pH class. In soils with pH greater than 6, the Olsen is again most similar to the mean followed by the KM and Bray methods.

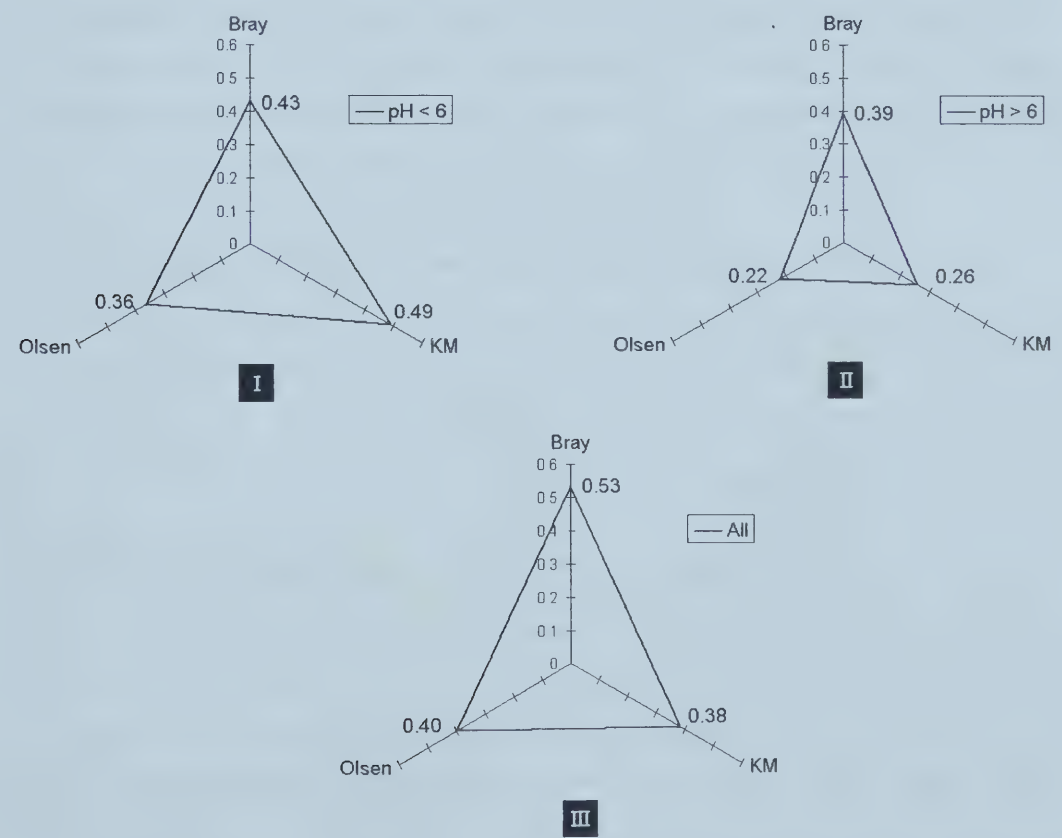


Figure 2-6. Dissimilarity plots for the three extraction methods according to pH class.

When all samples are considered at once, which is the objective of this study; Olsen and KM are virtually equidistant from the mean with coefficients of 0.40 and 0.38, while Bray is clearly the most dissimilar with a coefficient of 0.53. This suggests that either Olsen or KM would return the most reasonable P_a ranking for these soils.

However, comparing the dissimilarity coefficients using **Proc glm** in SAS (1999) using the Tukey’s studentized range test (conservative method) and the least significant difference (LSD) (liberal method) (Steel et al. 1997) result in no significant differences between the dissimilarity coefficients for these planned comparisons ($\alpha = 0.05$) suggesting that for this pH range, all three extraction methods return similar ranks.

2.6 Discussion and conclusion

2.6.1 IER and soil test methods

In-situ IER bags were correlated to neither the Olsen, KM nor Bray soil test methods for P_a . Although differences were anticipated between the two approaches (chemical extractant and in-situ ion exchange), the lack of correlation was surprising and disappointing. The results suggest that the differences between the two approaches results in each returning a measure of a different pool of the nutrient of concern. Table 2-3 outlines the major differences between the two approaches.

Table 2-3. Comparison of the IER and soil test methods for the determination of available nutrients.

	IER	Soil test methods
Measurement dynamic	Cumulative sink	Static
Sample type	Field in-situ	Lab homogenized
Controlled variables	Minimum	Maximum
Pool	‘actually’ available	‘potentially’ available
pH dependence	Independent	Dependent
Moisture dependent	No	Yes

The greatest limitation of the soil test method for the determination of P_a is the influence of soil pH on the pool quantified. In cases where wide ranges occur in a sample set, using two different methods (i.e. Olsen for high pH and Bray for low pH) yields numbers that can not be combined and compared. The alternative, using a single method for all samples brings into question the accuracy of the results (i.e. the underestimation of the P_a pool in calcareous soils using an acidic extractant).

IER bag results are limited as a result of uncontrolled variables during the incubation. Moisture regime, sluggish equilibrium dynamics and competition by plants and microorganisms control the P in soil solution available for accumulation on resin bags. The greatest limitation is in-situ

moisture regime limiting transport of available nutrients to the exchange resin. Soil moisture regime strongly affected resin ammonium values reported by Binkley (1984). Environment Canada (2001) reports the year 2001 as the 3rd driest year of the previous 54 years in the northwestern forest region at 18.6% lower than the running average precipitation. The lack of moisture at the burial depth likely reduced the efficacy of the IER bag method.

Another limitation of the bag method is the limited exposed surface area. Although there are many potential exchange sites available in each bag, the beads nearer to the surface of the bag are most likely to be exposed to the soil solution and the potential for exchange farther into the bag decreases with distance, especially in cases where moisture is limited.

IER membranes are becoming preferred over bags for use in lab and field, applied and research purposes (Abrams and Jarrell 1992; Qian and Schoenau 1995; Fernandes and Warren 1996; Hernández-Moreno and Negrín 1998; Nuernberg et al. 1998; van Raij 1998; Bentley et al. 1999; Fernandes et al. 1999) since they function as dynamic exchangers of nutrients rather than infinite sinks, require minimal soil disturbance (Fernandes and Warren 1996), are less tedious to prepare and analyze than bags and expose the entire exchange surface to soil solution and matrix.

Despite these limitations and the low correlation with the results from the conventional soil test methods the very high CV (%) results across all pH ranges indicate that IER bags are highly sensitive to on-site variables that extraction methods do not detect and are perhaps a better estimate of 'actually' available P given, for example, a moisture limitation that is real in the field.

IER methods are more appropriate where a longer term index is required, where soil test methods provide information about a single point in time. Soil test methods measure potential P_a whereas in-situ IER bags are dependent on on-site conditions in addition to potential P_a . When used together, they provide a measure of the relative contribution of each.

2.6.2 Soil test methods for determination of P_a

Each of the three evaluated soil extraction methods are strongly correlated with each other and any could be used across this pH range to rank soils in terms of P availability, although the KM method is more strongly correlated to Bray and Olsen than they are to each other. This combined with the high CV (%) results from the KM method, the lowest dissimilarity coefficient from the mean across the pH range from the KM method (despite the lack of statistical significance), and the commercial availability of the KM procedure in Alberta, it is concluded that the KM method is the most appropriate extractant for the determination of P_a in natural and reclaimed soils of the AOSR.

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CHAPTER 3: TOTAL P CONTENT AND ACCUMULATION OF C AND N IN BOREAL FOREST SOILS

3.1 Introduction

Newly exposed mineral materials undergo physical, chemical and biochemical weathering resulting in the alteration of the starting material, or parent material (PGM). Provided that neither sulfur (S) nor phosphorus (P) are limiting, carbon (C) and nitrogen (N) will be fixed from the atmosphere resulting in the accumulation of living and dead organic matter at the soil surface. Of the major components of soil organic matter (SOM), only P is almost entirely dependent on the content in the PGM. This combined with the key role of P in energy dynamics of plants and microorganisms and its limited solubility and mobility in soil has led to the hypothesis that the P content of PGM can govern the accumulation of organic matter. The objective of this paper is to explore the relationships between these elements in fine and coarse textured natural soils in the Athabasca Oil Sands Region (AOSR) of northeastern Alberta. With frequent disruption of the above ground organic matter (OM) in the region by fires, the OM preserved in soil provides the best organic pool to test this relationship.

3.2 Background

3.2.1 Ecological succession

All bare systems are subject to ecological succession, except perhaps those which are characterized by extreme moisture, temperature, light or parent material limitations (McIntosh 1981). Ecological succession is a universal ecological law (Clements 1977) being a unidirectional change in the composition of an ecosystem as the available competing organisms and especially the plants respond to and modify the environment (Merriam-Webster 2002).

Primary succession occurs when ecosystem development begins in an environment previously unaltered by living organisms characterized by a lack of organic matter (Clements 1977; Kimmins 1997). Two examples include fresh rock surfaces exposed by landslides and land created by lava flowing from volcanic eruptions. Secondary succession occurs in environments that have already been modified to some degree by some previous period of occupancy by living organisms (Kimmins 1997), for example, forest clear-cuts, abandoned agricultural fields (Kimmins 1997), eroded soils, soils influenced by changing elevation (subsidence or uplift), landslide, changing water table depth, human or animal impacts and fire affected soils (Clements 1977).

Deposits of till from the retreat of glaciers are often considered primary succession scenarios, but by definition could be considered secondary succession since the materials are not necessarily free from organic matter although they are considerably physically altered.

Reclaimed soils vary considerably in their physical and chemical properties. Whether succession following reclamation of soil is primary or secondary is debatable and largely dependent on the materials available. Successional patterns in natural ecosystems have been studied in the boreal forest (Larson 1980; Bryan-Davis 1981; Cottam 1981; Van Cleve and Viereck 1981; Loucks et al. 1981) and therefore can to a certain extent be predicted. The succession on by-products of industrial processes such as tailings sand is unknown.

3.2.2 Succession and pedogenesis

Succession and pedogenesis are inseparable and dependent on each other throughout ecosystem development (Binkley 1995) as illustrated by Figure 3-1.

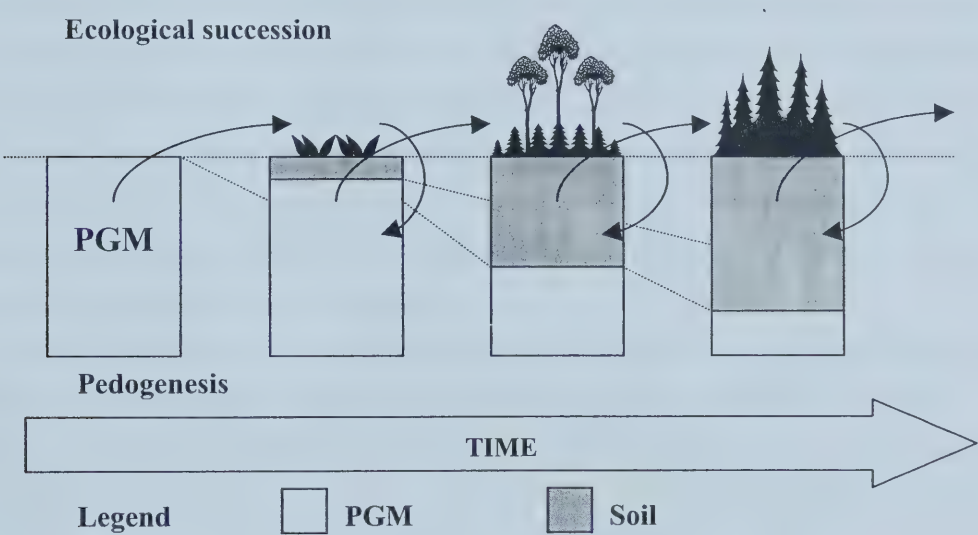


Figure 3-1. Schematic diagram illustrating the coupling between vegetation (ecological succession) and soils (pedogenesis).

Initially, inherent properties of soil PGM strongly influence the genesis of young soils (Yaalon 1975). As vegetative communities evolve, so do soils, and separating these two factors becomes increasingly difficult in mature communities because these factors are not independent. Furthermore, soil (or parent material) and vegetation are only two of the fundamental soil forming factors.

Hans Jenny (1941) identified five soil forming factors, or independent variables, for which different combinations result in different soils, only one soil can exist under each specific combination. The five factors are climate (*cl*), organisms (*o*), topography (*r*), parent material (*p*) and time (*t*) where the soil (*s*) is dependent on, or a function of (*f*) these factors as shown in Equation 3-1.

Equation 3-1.

$$s = f(cl, o, r, p, t)$$

Although expressed as a mathematical equation, quantitatively solving the fundamental soil forming equation is a difficulty at the center of soil science (Jenny 1941; Yaalon 1975). Separating the factors from each other (consider the complex relationship that exists between PGM and vegetation succession) and keeping them constant (consider the inherent variability within climate) are two challenges in solving soil forming or pedogenic functions.

3.2.3 P control of accumulation of soil organic matter

Organic matter is made up of C, hydrogen (H), N, P, S and oxygen (O), with N and P widely accepted as the two most frequently limiting nutrients in all forest ecosystems (Kimmins 1997; Fisher and Binkley 2000). Elements are available to ecosystems from two sources: the parent geologic material and the atmosphere. Initially, soil PGM in primary succession scenarios has no organic carbon (C_o) and organic $N^†$. Although rocks, sediments and coal contain from 96-98% of the N on the planet, virtually all of the balance (99%) is accounted for by atmospheric N (Paul and Clark 1996; Söderband and Sorenson 1976).

Unlike C, S and N, P has no gaseous phase leaving the phosphorus capital in soil dependent on the phosphorus content in the PGM and atmospheric deposition, the latter usually being negligible (Walker and Syers, 1976). This combined with the key role of P in energy dynamics of plants and microorganisms, as a component of ATP, and its limited mobility in soil makes P a unique component of SOM (Smeck 1973; Walker and Syers 1976).

According to Liebig's Law of the Minimum (Brady and Weil 1996), which states that plant production cannot exceed the level governed by the growth factor in the lowest amount relative to the amount optimum for that nutrient, it has been proposed that P content in the PGM has the potential to control SOM production and accumulation (Walker and Adams 1958; Walker 1964) over the longer term by controlling N_2 -fixation (Walker and Syers 1976) throughout soil development. All other factors being equal, soils with high P content will accumulate more organic matter than soils with lower P content. This concept has been supported by work done

[†] Since inorganic nitrogen is only a small component of N_t , N_i is used as an equivalent to organic N.

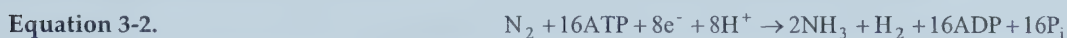
on chronosequences in New Zealand (Adams and Walker 1975; Adams et al. 1975) and Hawaii (Crews et al. 1995).

3.2.3.1 Nitrogen fixation

Soil N is almost entirely dependent on a huge atmospheric reservoir and the rate at which N can be fixed. The total amount of N in a soil reflects accumulation into the organic fraction over long periods of time, tending towards some equilibrium where annual additions balance the losses (Hausenbuiller 1985).

Nitrogen fixation is the conversion of nitrogen gas (N₂) from the atmosphere to ammonia and can occur biologically through symbiotic and non-symbiotic fixation, chemically through lightening discharge and photochemical reactions in the atmosphere, and anthropogenically through the production of N fertilizers (Hausenbuiller 1985).

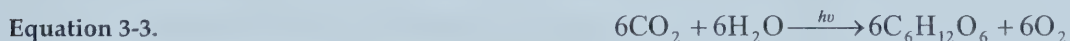
The fixation of nitrogen is an energy intensive process and is clearly dependent on P (Tisdale et al. 1993; Tate 2000b) as illustrated by Equation 3-2 (Brady and Weil 1996).



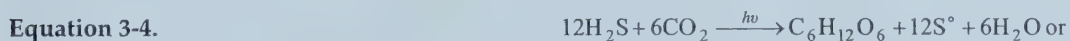
The Adenosine Tri-Phosphate (ATP) required in less than ideal conditions is closer to 20 or 30 ATP molecules which is roughly equivalent to the energy gained by the oxidation of one molecule of glucose (Tate 2000b). The ATP supporting N₂-fixation comes primarily from heterotrophic and phototrophic N₂-fixers (Tate 2000b).

3.2.3.2 Carbon fixation

The fixation of organic carbon and solar energy ($h\nu$), like N, is dependent on the large atmospheric reservoir of C as CO₂. Carbon is fixed in organic molecules (the carbohydrate glucose) through oxygenic photosynthesis according to Equation 3-3.



Anoxygenic photosynthesis proceeds according to Equation 3-4 or Equation 3-5.



Although anoxic photosynthesis was important in early earth history, oxygenic photosynthesis now dominates (Staley and Orians 1992).

The reciprocal process is that of respiration whereby organisms oxidize carbohydrates for energy stored in C-H bonds. For organic carbon (C_o) to accumulate in soil, net photosynthesis must exceed respiration.

Non-symbiotic N₂-fixation by heterotrophic organisms in primary succession is limited by the lack of available carbon substrate. Autotrophs, specifically cyanobacteria (formerly blue-green algae) are able to fix both C and N through the process of photosynthesis (Hausenbuiller 1985; Dart and Day 1975; Atlas and Bartha 1993) and would be responsible for initial C_o and N accumulation in soil when N limits plant growth. Once sufficient fixed N and C_o have accumulated, N₂-fixing organisms would decline as they are poor competitors with heterotrophic bacteria; additional N₂-fixation would proceed symbiotically (Tate 2000b), and the energy stored in SOM would drive the microbial community (Tate 2000a).

That organic C and N accumulate in soil during pedogenesis has been documented by many through work on chronosequences. Crocker and Major (1955), Crocker and Dickson (1957), Olson (1958), Jacobson and Birks (1980), Fitter and Parsons (1987), Chapin et al. (1994) and VandenBygaart and Protz (1994) all report significant increases in total N and C of chronosequences on retreating glaciers or stabilizing sand dunes in Canada. C and N accumulation has also been documented in disturbed or reconstructed soils. For example Anderson (1977) documents the accumulation of C and N in glacial till mine spoils in Saskatchewan, and Hallberg et al. (1978) document C accumulation in exposed Wisconsinan loess in Iowa.

3.2.3.3 SOM pools

The succession of forests in central and northern Alberta is controlled by fire at intervals ranging from 50 to 200 years, altering the above-ground nutrient pool (Fyles 1986) and potentially significantly altering the C:N:P ratios of the LFH (for example Raison et al. 1985; de Ronde and Stock 1994; Mackensen et al. 1996). The long-term supply of nutrients that support ecosystem processes is dependent largely on accumulated nutrients in the soil because nutrient pools maintained in the vegetation are subject to loss or are returned to the soil during fires (Fyles 1986). The SOM preserved in the shallow mineral soil is more likely to represent historical differences between ecosystems than the more dynamic pool held in above ground vegetation (Fyles 1986) or in the LFH making it a the most reasonable pool to test the influence of P. The LFH composition may be more reflective of the fire history of the area or the recent additions of litter than the influence of P, or other factor(s).

3.2.4 P transformations and availability during pedogenesis

The primary successional P transformation model (Williams and Walker 1969; Walker and Syers 1976; Figure 3-2) illustrates P transformations as a function of time, where increasing time can be

substituted with decreasing pH according to the solubility of phosphate compounds as established by Lindsay and Moreno (1960). Vitousek and White (1981) couple this model with the theoretical pedogenic N₂-fixation model of Gorham (1981).

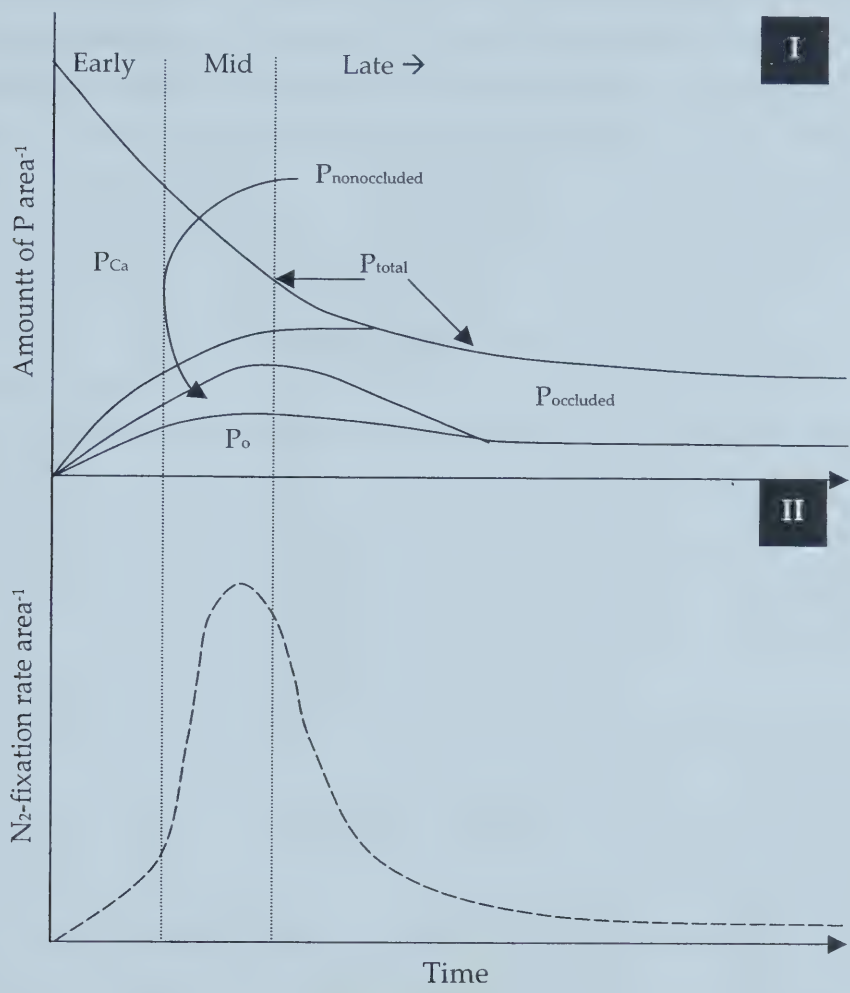


Figure 3-2. Primary successional P transformation model after Walker and Syers (1976) and theoretical N₂-fixation rate model after Gorham (1981).
 P_t = total P in soil; P_{Ca} = Ca-bound be in primary minerals and secondary minerals that can form at high pH; P_o = organic P; P_{nonoccluded} = solution P, relatively available P, reversible sorbed P; P_{occluded} = virtually irreversible fixed P; Early, Mid and Late refer to soil pedogenic stage proposed in Table 3-1.

In early development, the low solubility of primary P-bearing minerals controls the N₂-fixation rate and therefore the C and N (and P_o) accumulation in young soils. P limitation in young soils has been documented where P availability is low due to the slow release from primary minerals, for example in young volcanic sites in Hawaii (Vitousek 1999). Walker and Adams (1958),

Walker (1964) and Walker and Syers (1976) report P limitation in old, highly weathered soils in New Zealand where P availability is limited due to the transformation of sparingly soluble forms of P to insoluble occluded P which would limit N₂-fixation, plant growth and microbial activity. This stage is also marked by a decrease in P_o. In mid-pedogenic development, P is becoming increasingly available, increasing the P_a:P_i ratio. Since N₂-fixation is dependent on an adequate supply of P_a, N₂-fixation would be highest during this phase when P_a is most available and P_o is permitted to accumulate. In late pedogenic development, P_a is limiting and P_o is not permitted to accumulate and the P_o pool becomes critical for maintaining site productivity. If P_o is lost from the system, the P_o pool can be degraded.

Thus, three soil development stages are proposed and their distinguishing characteristics are outlined in Table 3-1.

Table 3-1. Characteristics of proposed soil developmental stages (extended from Vitousek and White 1981).

	P-stress	N ₂ -fixation	P _a	P _o	pH	Mechanism for limitation
Early	✓	Limited by ↓P _a	Limiting	Slow accumulation	Highest	P _a limited by low solubility of 1° minerals
Mid	✗	↑	Not limiting	Accumulation		-
Late	✓	Limited by ↓P _a	Limiting	Depletion	Lowest	P _a limited by: Insolubility of occluded secondary minerals, Loss of P through leaching, runoff and erosion, and fires.

Phosphorus limitation in temperate and tropical forests has been extensively documented (Kimmins 1997; Fisher and Binkley 2000) however forest growth at high latitudes or at high elevations is more often limited by N (Kimmins 1997), that is, growth response to N fertilization is positive. Vitousek and White (1981) propose that most temperate glaciated regions are in the mid-pedogenic stage of development where N:P ratios are similar to those required for plant growth. Still, it is reasonable to propose, given that N₂-fixation is largely dependent on an available supply of P_a, that N is in short supply because P has limited its accumulation or that it currently limits the microbial activity required to mineralize the N accumulated in OM to plant usable forms.

3.3 Objective

The objective of this study was to examine the relation of total P in fine and coarse textured soils in north-eastern Alberta to the accumulation of C and N in SOM.

3.4 Study area

Sites are located in the Athabasca Oil Sands Region (AOSR) in northeastern Alberta, ranging from 56° and 59°N latitude and 113° and 110°W longitude (Figure 3-3).

3.4.1 Climate

The climate of northern Alberta is cool continental, subarid to subhumid characterized by long cold winters and marked differences between day and nighttime temperatures (Beckingham and Archibald 1996). Mean annual temperature is 1.5°C, with an average annual precipitation of 389mm and 1147 growing degree days (Beckingham and Archibald 1996).

3.4.2 Soils

The soils in this study area occur on late Wisconsinan age glacial deposits including the Dover and Kinosis tills and glaciofluvial outwash sands (Spiers et al. 1989). The soils developed on these parent materials are generally Orthic Gray Luvisols on the lacustrine tills and Eutric and Dystric Brunisols on the sands. Soil classification data can be found in Chapter 4, detailed soil chemical data can be found in Appendix C and soil profile descriptions in Appendix D.

3.4.3 Vegetation

Northeastern Alberta is part of the boreal mixedwood (BM) ecological area, as described by Beckham and Archibald (1996) and the mid boreal mixedwood ecoregion, as described by Strong and Leggat (1992). The fine textured Luvisolic soils were mixedwood stands characterized by trembling aspen (*Populus tremuloides*) (the dominant tree species in the region) and balsam poplar (*Populus balsamifera*), white spruce (*Picea glauca*), with the occasional balsam fir (*Abies balsamea*) and white birch (*Betula papyrifera*). Jackpine (*Pinus banksiana*) dominated on the dry, sandy Brunisols with trembling aspen, in some cases. Detailed vegetation data can be found in Appendix E and summarized classifications can be found in Chapter 4.

3.5 Methods

3.5.1 Site selection

Ten fine textured sites and ten coarse textured sites were selected from a network of monitoring and research plots established in the region (Appendix A) extending north to the 22 km post on the Fort Chipewean winter road and south to near the Highway 63 intersection of the Hangingstone River (Figure 3-3).

Sites were selected based on their textural suitability as natural analogues for comparison in reclaimed soils in the AOSR (Chapter 4) and all were upland, moderately well to well drained sites of similar age.

3.5.2 Soil sample collection and preparation

Soil investigations were performed to 1 m depth at each of 44 sites during June and July of 2001. One soil sample was collected by each morphological horizon in each pit. Collected mineral samples were stored in plastic bags and air dried the same day. The fine earth fraction (<2 mm) was retained for chemical analyses. LFH samples were dried at 70°C for 48 hours and ground to pass a 2 mm screen. Coarse fragments were removed and adjustments were made where the percent coarse fragments exceeded 5%.

Available nitrogen (N_a): N_a was extracted using 2 M KCl at a 5:1 extractant:soil ratio according to Maynard and Kalra (1993) and NH₄-N (Technicon 1973a) and NO₃-N (Technicon 1973b) were determined colorimetrically using a Technicon TM Autoanalyzer II automated colorimetry system. The NO₃-N determination includes NO₂-N in sample.

Available P (P_a): The modified Kelowna (KM) (Ashworth and Mrazek 1995) solution was selected as the most suitable extractant for the determination of P_a (Chapter 2). P_a was extracted using the KM solution and PO₄-P determined colorimetrically (Murphy and Riley 1962) on the extract using a Technicon TM Autoanalyzer II automated colorimetry system (1973c).

Total and organic carbon, total nitrogen and total phosphorus: Prior to total phosphorus (P_t), total nitrogen (N_t), inorganic carbon (C_i) and organic carbon (C_o) analyses, samples were finely ground to a homogenous powder in a Mixer Mill, MM2 ball grinder from Brinkmann Instruments Co.

P_t was determined colorimetrically (Murphy and Riley 1962) after H₂SO₄ digestion using a Technicon Autoanalyzer (1977) automated colorimetry system. N_t and C_t were determined by a Carlo-Erba Dumas combustion instrument. C_o was calculated as the difference between the C_t and the C remaining following acidification with 6 M HCl.

Equation 3-6.

$$\text{Organic C} = \text{Total C} - \text{Total C (HCl acidification)}$$

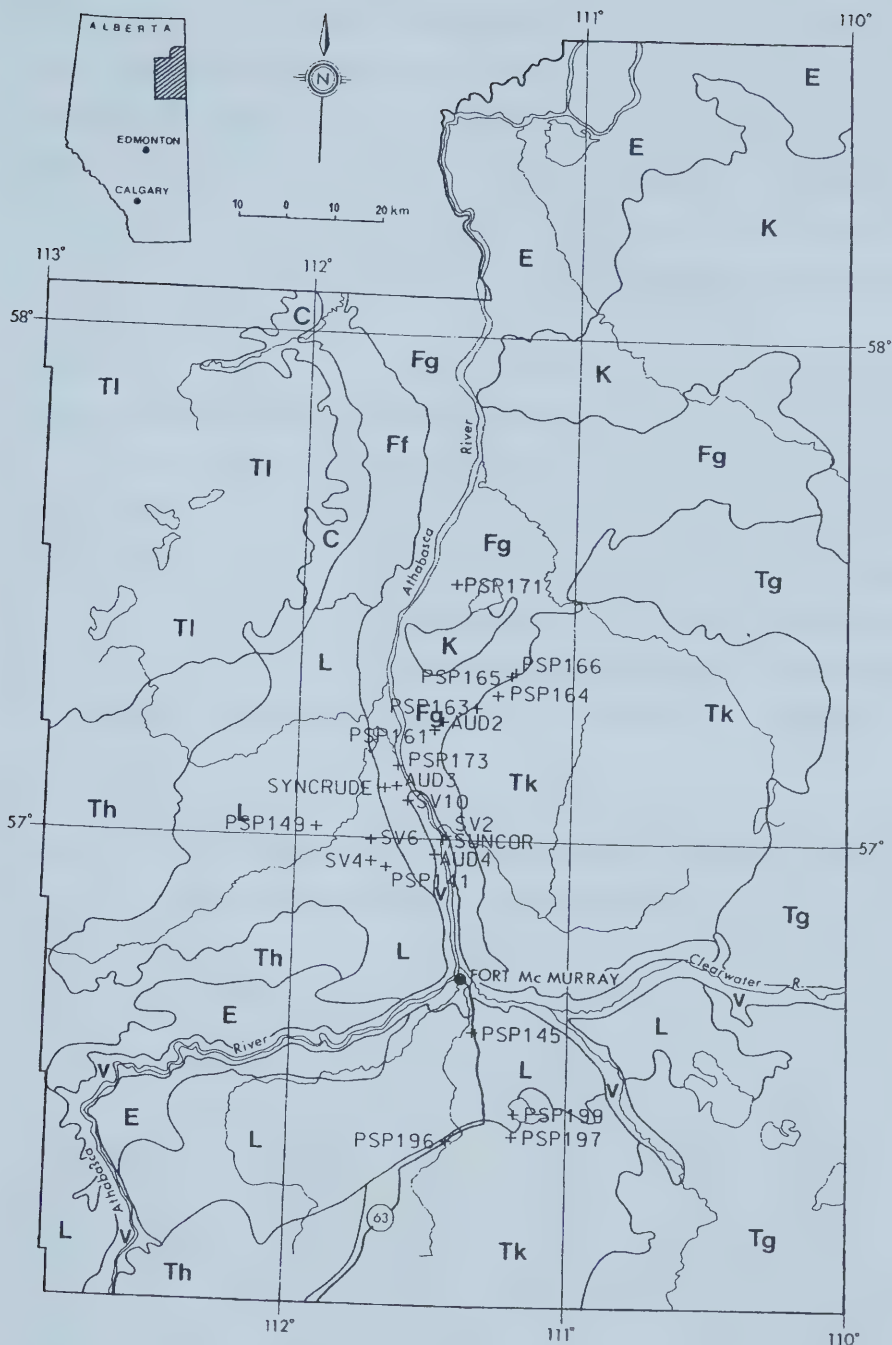


Figure 3-3. Study sites and surficial geology of the AOSR (map from Spiers 1989).

L=Dover glaciolacustrine clay and silt; Tg=Gypsy till; Tk=Kinosis till; Th=Horse River till; TI=Legend till. V=erosional gullies and valleys; C=colluvial mixed bedrock and glacial material; E=eolian sand; Ff=fluvial fan deposits; Fg=glaciofluvial outwash sand; K=glaciofluvial outwash sand and gravel. += site locations, Syncrude Canada Ltd. Mildred Lake mine and Suncor Energy mine site.

Organic phosphorus (P_o): P_o was determined by subtracting P_i from P_t determined by H₂SO₄ digestion above. P_i was extracted from one-gram samples (<2mm) of soil extracted with 50 ml 0.1 M H₂SO₄ in open Erlenmeyer flasks on a G10 Gyrotron® Shaker (New Brunswick Scientific Co., Inc.) bed shaker for two hours at approximately 229 rpm. Samples were filtered with Whatman 41 filter paper and P concentration in the filtrate was determined colorimetrically (Murphy and Riley 1962) using a Technicon TM Autoanalyzer II (1973c) automated colorimetry system. The P_o was calculated using Equation 3-7.

3.6 Results

Amounts of the various forms of C, N and P determined are presented in Table 3-2.

Depth (cm)	Nitrogen		Phosphorus			Carbon	
	N _{total} kg ha ⁻¹	N _{available}	P _{total}	P _{available} kg ha ⁻¹	P _{organic}	C _{total} Mg ha ⁻¹	C _{organic}
Coarse (<i>n</i> = 10)							
9-0	394±21	5.7±0.4	33.6±1.7	5.4±0.4	26.0±1.2	12.7±0.6	12.5±0.6
0-20	597±10	4.5±0.1	374±19	60±6.8	221±7.9	8.4±0.3	7.50±0.3
9-0-20	991±29	10.2±0.4	407±19	65.7±6.6	247±8.0	21.1±0.6	20.0±0.5
20-100	2437±111	12.2±0.5	2395±164	390±49	896±28	61.0±9.9	53.1±8.7
Total	3428±117	22.4±0.9	2802±156	456±49	1143±33	82.0±9.8	73.2±8.6
Fine (<i>n</i> = 10)							
13-0	1351±79	29.6±2.4	113±7.6	21.1±1.2	77.5±4.9	37.8±1.7	37.3±1.7
0-20	1734±77	11.8±0.4	623±30.6	16.1±2.2	430±21	22.9±1.4	22.7±1.4
13-0-20	3085±115	41.4±2.3	737±33.7	37.2±2.5	507±22.8	60.7±2.3	60.1±2.3
20-100	5424±99	32.6±2.1	3223±93	36.8±2.2	1435±75	112±6.6	71.3±1.0
Total	8509±182	73.9±3.2	3959±118	74.0±3.8	1943±91	172±6.4	131.3±2.6

[†] The concentration of H^+ in the extracting solution is 0.1, making the pH 1: $(-\log[0.1] = 1)$.

Statistical comparisons of these amounts to each other and to reclaimed soils are presented in Chapter 4 with discussion on detected differences.

3.6.2 Nutrient ratios

Select ratios between elements were calculated for the LFH, 0-0.2 m depth and 0.2-1.0 m depth and are presented in Table 3-3.

Table 3-3. Mean nutrients ratios for fine and coarse textures soils in northeastern Alberta.

Depth (cm)	P _a :P _i	C _o :P _o	N:P _o	P _o :P _i	C _o :N
Coarse (<i>n</i> = 10)					
LFH (13-0)	0.15	501	15	5.1	34
0-20	0.13	85	4	5.0	21
20-100	0.14	71	3	1.6	19
Fine (<i>n</i> = 10)					
LFH (9-0)	0.20	523	18	2.4	29
0-20	0.05	128	6	3.6	19
20-100	0.02	79	5	1.3	16

P_a is a consistent proportion of P_i with depth in the coarse textured profiles, whereas in the fine soils it decreases to a mere 2% at depth. The C_o:P_o ratios are high (>500) in the LFH horizons with values close to 100 for the mineral horizons. The N:P_o ratios follow a similar pattern, being 15 and 18 in the LFH and 6 or less in the mineral soil. The P_o:P_i ratios are higher in the LFH and top 0.2 m of the profile, but on average, P_o exceeds P_i even at depth. The C_o:N ratios are less than twice as large in the LFH as the mineral soil.

3.6.3 Linear regression

Simple linear regressions were used to examine relationships between elements using **Proc reg** (SAS 1999). Regressions were performed by soil type (fine or coarse) and on all soils (all=fine and coarse) for a variety of relationships and results are presented in Table 3-4.

Relationships between C_o, N and P_o in LFH: Strong significant relationships were found in the fine and coarse textured soils between C, N and P in SOM (Table 3-4: rows 1-3). Grouping soils together results in a significant but slightly lower relationship between P_o and C_o indicating that the P_o:C_o ratios between the two textural groups are slightly different. In general, C, N and P are associated in fairly definite proportions in SOM, the relationship between C_o and N being stronger than P_o and N or P_o to C_o.

Relationships between C_o, N and P_o in the shallow mineral soil: Relationships between C, N and P in SOM of the shallow mineral soil are significant but not as strong as those in the LFH (Table 3-4: rows 4-6). C and N are held in close relationship in the fine textured soil (R² = 0.92) but they are not held in definite proportions in the coarse textured soils (R² = 0.31). The coarse

textured soils have a close relationship between P_o and C_o in the shallow mineral soil ($R^2 = 0.70$) in contrast to no relationship in the fine textured soils ($R^2 = 0.07$). P_o tends to be associated with N fairly closely if all soils are compared, but not if they are taken individually.

Table 3-4. R^2 -values for regression analyses of various relationships in fine and coarse textured soils of northeastern Alberta.

Regression†		Fine (n=10)	Coarse (n=10)	All (n=20)
Relationships between C_o , N and P_o in LFH				
1	$[P_o]_{LFH}$ vs. $[N]_{LFH}$	0.88*	0.69*	0.82*
2	$[N]_{LFH}$ vs. $[C_o]_{LFH}$	0.99*	0.92*	0.98*
3	$[P_o]_{LFH}$ vs. $[C_o]_{LFH}$	0.77*	0.78*	0.71*
Relationships between C_o , N and P_o in shallow mineral soil				
4	$[P_o]_A$ vs. $[N]_A$	0.24	0.10	0.47*
5	$[N]_A$ vs. $[C_o]_A$	0.92*	0.31	0.88*
6	$[P_o]_A$ vs. $[C_o]_A$	0.07	0.70*	0.30*
Relationships between P_t to 1 m and C_o , N and P_o in LFH				
7	P_{1m} vs. P_o_{LFH}	0.33	0.09	0.28*
8	P_{1m} vs. N_{LFH}	0.31	0.11	0.29*
9	P_{1m} vs. C_o_{LFH}	0.37	0.05	0.30*
Relationships between P_o in LFH and P_t from 0-0.2 m and 0.2-1.0 m depths				
10	P_o_{LFH} vs. $P_{0-0.2m}$	0.30	0.09	0.19
11	P_o_{LFH} vs. $P_{0.2-1m}$	0.14	0.02	0.36*
Relationships between $[P]_C$ and C_o , N and P_o in LFH				
12	$[P]_C$ vs. $[P_o]_{LFH}$	0.01	0.22	0.04
13	$[P]_C$ vs. $[N]_{LFH}$	0.04	0.05	0.01
14	$[P]_C$ vs. $[C_o]_{LFH}$	0.06	0.11	0.00
15	P_{1m} vs. $[P]_C$	0.13	0.26	0.30*
Relationships between $[P]_C$ and C_o , N and P_o in shallow mineral soil				
16	$[P]_C$ vs. $[P_o]_A$	0.55*	0.18	0.26*
17	$[P]_C$ vs. $[N]_A$	0.20	0.00	0.29*
18	$[P]_C$ vs. $[C_o]_A$	0.06	0.02	0.15
19	$[P]_A$ vs. $[P]_C$	0.12	0.26	0.04
Relationships between P_t within profiles				
20	P_{LFH} vs. P_{1m}	0.34	0.22	0.31*
21	P_{LFH} vs. $P_{0-0.2m}$	0.31	0.23	0.21*
22	P_{LFH} vs. $P_{0.2-1m}$	0.25	0.09	0.35*
23	$P_{0-0.2m}$ vs. $P_{0.2-1m}$	0.40*	0.24	0.05

* indicates a significant linear regression $\alpha = 0.05$

† [] denotes concentration in (ppm); otherwise amounts (mass area⁻¹)

Relationships between P_t and C_o , N and P_o in LFH: Significant, however weak, relationships were detected between C_o , N and P_o in the LFH and the P_t to one meter including the amount accumulated in the LFH (Table 3-4: rows 7-9). The P_o in the LFH is not related to the P_t in the top 0.2 m of the mineral soil but is weakly correlated to the amount of P_t from 0.2 to 1 m depth when soils are grouped together (Table 3-4: rows 10&11).

Relationships between the concentration of P in the C horizon and C_o , N and P_o in LFH: There are no significant relationships between the concentration of P in the PGM and concentrations of C_o , N and P_o in the SOM accumulated in the LFH. The P_t to 1 m is only weakly correlated to the concentration of P in the C horizon ($[P]_c$) Table 3-4: rows 12-15.

Relationships between the concentration of P in the C horizon and C_o , N and P_o in the shallow mineral soil: A weak but significant relationship exists between the concentration of P in the C horizon and concentration of P_o in the shallow mineral horizon if all soils are grouped together (Table 3-4: row 16) and the concentration of N in the shallow mineral soil (Table 3-4: row 17). The concentrations of C_o and P_t in the shallow mineral soil are not related to the concentration of P_t in the C horizon (Table 3-4: rows 18&19).

Relationships between P_t within profiles: There are no significant relationships between the P_t in the LFH and the P_t to 1 m, the P_t from 0-0.2 m, or the P_t from 0.2-1.0 m of the profile within the fine and coarse textural groups, but significant relationships were detected when all soils were grouped together (Table 3-4: rows 20-22). The fine textured soils are more uniformly distributed in terms of P_t than the coarse textured soils since the material in the top 0.2 m of the profile is related to the material in the bottom 0.8m of the profile for the fine soils, but not for the coarse (Table 3-4: row 23).

3.7 Discussion

3.7.1 Relationships between P_t and accumulated C_o , N and P_o

Relationships between amounts of P_t to 1 m and to 0.2 m and concentrations of P_t in the C horizon to the C_o , N and P_o accumulated in the LFH and preserved in the SOM of the shallow mineral soil are weak at best. This suggests that P is not the sole or primary limiting factor for SOM accumulation in these soils. This is consistent with the proposition of Vitousek and White (1981) that these soils are in a mid-pedogenic stage of soil development where P is not limiting. Two important factors, however, lead to uncertainty in this conclusion: 1) the potential lack of parent material uniformity, and 2) the potentially high inputs and losses of P to the systems.

3.7.1.1 Parent material uniformity

Parent material uniformity is desired when attempting to solve pedogenic functions. Results presented above and soil profiles presented in Chapter 4 provide evidence that fine textured soils are more uniform than the coarse textured soils in terms of P_t . The P_t of all soils, fine and coarse, are at best only weakly correlated to the concentration of P in the C horizon. Soils are either 1) variable due to depositional dynamics, or 2) that current variability reflects significant translocation of P within the soil profiles or net losses of P from profiles.

There exists evidence to support both processes, but it is impossible with the data collected to separate them. Variability within and among coarse soil profiles is evident in soil profile descriptions in Appendix D. Two sites (PSPs 197 and 166) are outwash sand veneers over glaciolacustrine material, PSP 161 has a fine textured lens at 0.9 m depth, SV 2 is dominantly a sandy loam versus a sand for all other sites and AUD 2 has 40% stones and is impregnated with oil. Data presented in Chapter 4 provide evidence for transformation and translocation of P in the coarse textured soils. The accumulation of P in Bm horizons is evident and most strongly expressed in PSPs 162 and 197 and in SV2.

3.7.1.2 Potential gains and losses of P

Atmospheric deposition of phosphorous in the region appears small, ranging from 0.06 to 0.74 kg $ha^{-1} yr^{-1}$ in Canadian forests (Kimmins et al., 1985; Cole and Rapp 1980; Scheider et al. 1976; Schindler et al. 1979) and 0.20 $ha^{-1} yr^{-1}$ in north-central Alberta (Shaw et al. 1989). This translates to 0.6 to 7 Mg ha^{-1} over the course of 10,000 years, which is huge when compared to values of P_t to 1 m from Table 3-2.

Leaching out of the rooting depth of a spruce forest on a sand moraine in the USSR was reported at 0.06 kg $ha^{-1} yr^{-1}$ (0.6 Mg ha^{-1}) with 650 mm of annual precipitation (Cole and Rapp 1981). Xiao et al. (1991) show in soils of similar age, climate and PGM as the fine textured soils in this study lost 40% of original P_t from the soil profiles during soil development. Cole and Rapp (1981) report stream runoff of P between 0.01 and 0.6 kg $ha^{-1} yr^{-1}$, (0.1 and 6 Mg ha^{-1}). The magnitude of potential losses is high compared to P_t values from Table 3-2.

The variability in the P distribution of the original PGM and the unquantified but potentially significant inputs and losses make an arbitrary selection of an assessment depth (i.e. 1 m) inadequate because the actual depth to which plants are using P is unknown. One can no longer be confident that the material at 0.2m depth was the same as the material in the C horizon at time

0, leading to uncertainty when interpreting relationships between the surface pools and the C horizon or total amount of P to 1 m.

3.7.2 Relationships between C_o , N and P_o in OM of LFH and shallow mineral soil
 C_o , N and P_o are closely associated in the LFH with the relationship between C_o and N being the strongest, followed by P_o and N and P and C_o last. This indicates that P_o is not associated in definite proportions in the LFH. The $C_o:N$ and $C_o:P_o$ ratios of the LFH horizons are highly reflective of the largely undecomposed vegetative component.

These high $C_o:P_o$ ratios (>500) and moderately high $C_o:N$ ratios (29 and 34) in the LFH material indicate that these layers in themselves are stressed for P and to a lesser degree N. Fungi are primarily responsible for the decomposition of forest litter and have wide C:N ratios (4.5:1 to 15:1) compared to bacteria (3:1 to 5:1) which are primarily responsible for decomposition of agricultural residues (Paul and Clark 1996). The $C_o:N$ ratios of the LFH materials are high and would likely result in the immobilization of N by bacteria, but forest soil microbial populations can show net mineralization of substrate with $C_o:N$ ratios as high as 100:1.

Predicting the net mineralization/immobilization of P using the $C_o:P_o$ ratio is not widely accepted since P_o determination can include significant amounts of P_i (Dalal 1977; Chapter 3, Section 2.2.1.2). Still, a $C_o:P_o$ ratio of 300:1 or greater is extensively reported in the literature as the point where P will be immobilized (Alexander 1977; Dalal 1977; Brady and Weil 1995).

If P_i is provided in sufficient amounts to fuel microbial decomposition of the LFH, the $C_o:N$ and $C_o:P_o$ ratios of residual preserved OM would be expected to narrow. If available P_i (P_a) is not provided in sufficient amounts (i.e. P-stress) P_o would be actively hydrolyzed to supply P_i for growth (McGill and Cole 1981). In such cases, P_o would tend not to accumulate, $P_o:P_i$ ratios would tend to be smaller and $N:P_o$ would be higher. For example, consider the drop in the $N:P_o$ ratio from a Brown to a Black Chernozem in Alberta from 14 to 10 and the increase in the $P_o:P_i$ ratio from 0.5 to 1.0 (as calculated by McGill and Cole, 1981 using data from Dormaar and Webster, 1963).

The $P_o:P_i$ ratios in the shallow mineral soil are as high or higher than in the LFH. If the systems were stressed for P, one would expect that P_o would not accumulate or be preserved in the mineral soil. The $N:P_o$ ratios drop by more than half from the LFH to the shallow mineral soil, providing additional evidence for P_o preservation in the OM of the shallow mineral soil.

The $C_o:P_o$ and $N:P_o$ ratios in SOM have narrowed substantially from the LFH to the shallow mineral soil. C_o declines while P_o is preserved, characteristic of a system not stressed for P.

3.8 Conclusion

The accumulation of C, N and P in upland, well drained fine and coarse textured soils of northeastern Alberta was found to be weakly correlated to the total amount of P to 1m depth and the concentration of P in the PGM. This suggests that P is not the primary limiting factor for SOM accumulation at this stage of soil development. According to the model of McGill and Cole (1981) the ratios of $C_0:P_0$, $N:P_0$ and $P_0:P_i$ further suggests a system that is not stressed for P.

Although P likely limited C and N accumulation in early soil development (weak relationship to P to accumulated C and N) currently the systems are not stressed for P.

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CHAPTER 4: FORMS, AMOUNTS AND DISTRIBUTION OF C, N AND P IN NATURAL AND RECLAIMED SOILS OF THE ATHABASCA OIL SANDS REGION

4.1 Introduction

The goal of reclamation in the Athabasca Oil Sands Region (AOSR) of northeastern Alberta is to develop strategies that will lead to self-sustaining ecosystems of equivalent land capability to the ecosystems present prior to disturbance. This includes the development of ecosystems capable of supporting commercial forests and sustaining the impacts of forest harvesting. Materials used for reclamation in the region are carefully screened and handled to ensure comparable physical and basic chemical properties such as clay content, bulk density, pH, electrical conductivity (EC) and sodium adsorption ratio (SAR).

Results from research exploring the amounts and availability of nutrients are mixed. Data from Macyk and Turchenek (1995) comparing tailings sand (TSS) to natural sands indicate that natural sands (of varying depth) have around five times as much total phosphorus (P_t) as does the TSS and that available phosphorus (P_a) was consistently below the detection limit in TSS. Aside from phosphorus (P), very few differences between the natural sands and TSS except the higher pH in the TSS were detected (pH, cation exchange capacity (CEC), total exchangeable cations (TEC), organic carbon (C_o) and nitrogen (N), oil content total and available nutrients, toxicity, saturated paste extract properties, DTPA[†] extractable elements and total elemental analyses were performed on samples).

In a preliminary study to examine total and available nutrients in natural and reconstructed ecosystems in the AOSR, it was reported P_t contents in reconstructed soils were comparable to natural analogues in the AOSR but that available phosphorus (P_a) values tended to be less than in natural analogues, suggesting that the reclaimed soils may have a diminished capability for providing P_a (OSSVWG 2001). These findings are encouraging, in terms of P_t , but investigations were limited to the top 0.2 m of the soil profiles making comparisons to Macyk and Turchenek's work (1995) difficult.

The present study characterizes and compares various forms, amounts and distributions to 1 m depth of carbon (C), N and P in natural and reclaimed soils in the region, with special emphasis on P because of its dependence on the starting materials for total nutrient capital and its importance in biochemical cycles.

[†] diethylenetriamine penta-acetate

4.2 Objectives

The objective is to determine if there exist differences between the forms, amounts and distribution of C, N and P 1) between natural and reclaimed soils, 2) between fine and coarse textured natural and reclaimed soils, and 3) between overburden (OB) and tailings sand (TSS)[†] reclamation prescriptions. Differences in the amounts of the various forms of the elements will be analyzed statistically. The variability in the distribution within the soil profile will be evaluated more qualitatively.

4.3 Background

4.3.1 Study area

4.3.1.1 Site locations

The AOSR is located in northeastern Alberta, ranging from 56° to 59°N latitude and 110° and 113° W longitude. Reclaimed soils ($n=24$) were investigated at the Syncrude Canada Ltd. Mildred Lake and the Suncor Energy mine sites. Syncrude is located approximately 35 km north of Fort McMurray and Suncor is located approximately 20 km north of Fort McMurray on Highway 63 (Figure 4-1). Undisturbed sites ($n=20$) were selected from a network of monitoring and research plots established in the region (Appendix A) extending north to the 22 km post on the Fort Chipewean winter road and south to near the Highway 63 intersection of the Hangingstone River (see Figure 3-3, Chapter 3).

4.3.1.2 Climate

The climate of northern Alberta is cool continental, subarid to subhumid characterized by long cold winters and marked differences between day and nighttime temperatures (Beckingham and Archibald 1996). Mean annual temperature is 1.5 °C, with an average annual precipitation of 389 mm and 1147 growing degree days (Beckingham and Archibald 1996).

4.3.1.3 Geology

4.3.1.3.1 Western Canadian oil sand deposits

The Athabasca oil sand deposit is one of the world's largest petroleum reserves and one of four in Alberta, Canada (see Figure 4-1). The Athabasca deposit has an aerial extent > 48 000 km² containing an estimated one trillion barrels of heavy bitumen (Humphreys and Schutte 1978) potentially yielding in the order of 625 billion barrels of oil (Selley 1978).

[†] For descriptions of the reclamation prescriptions and materials examined in this study, see Figure 4-3 and Figure 4-4. OB reclamation is considered fine and TSS reclamation is considered coarse textured prescriptions in the experimental design (Figure 4-5).

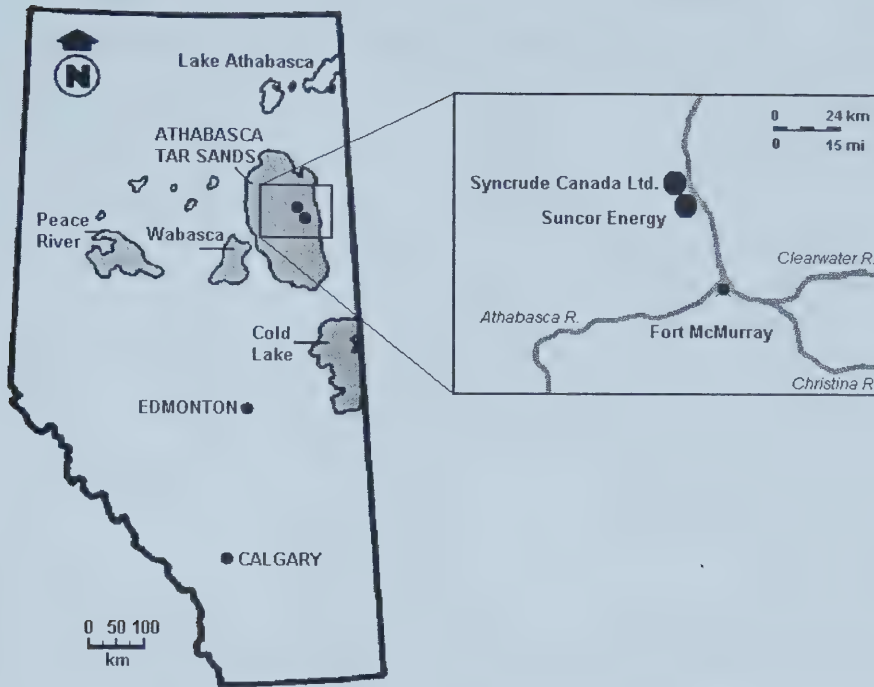


Figure 4-1. Location of study area relative to the lower Cretaceous oil sand formations in Alberta, Canada (base map adapted from Jardine 1974; Nyren and Mittal 1979; Conoco Inc. 2002).

4.3.1.3.2 Regional stratigraphy

The oil sand in the Athabasca deposit is contained in the lower member of the McMurray (K_m) formation, lower Mannville group (Figure 4-2). Overlying the oil sand ore are a series of Cretaceous deposits, followed by an erosional unconformity, ending with Pleistocene and Holocene deposits. The late Wisconsin glaciation obliterated or masked any evidence of previous glaciations with fresh landforms and deposits (Trenhaile 1990), which characterize many of the recent deposits in the region.

The depth to the McMurray formation ranges from zero to 700 meters. This overlying material is termed overburden (OB) and increases in thickness in the southwest direction. The thickness of the formation ranges from only a few to 60 meters (Humphreys and Schutte 1978).

EON	ERA	PERIOD	STRATIGRAPHY			LITHOLOGY	
			Group	Formation	Member		
Phanerozoic	Cenozoic	Holocene	H _e			Erosional features and sediments	
			H _o			Muskeg, peat beds and highly organic mineral soil	
			H _l			Lakeshore and lake-bottom deposits	
			H _f			Alluvial deposits of sand with clay lenses and clay with sand lenses	
			H _{ae}			Aeolian sand in sheet or dune form	
		Pleistocene	P _l			Glaciolacustrine deposits: sands, silts and clays	
			P _f			Glaciofluvial deposits: meltwater channel sediment, outwash sands and outwash sands and gravels	
			P _g			Glacial till deposits: undifferentiated	
		Pliocene	-			Pre-glacial sands and gravels	
		Erosional Unconformity					
	Mesozoic	Cretaceous	Upper	Colorado	La Biche (K _{lb})		Shale
					Dunvegan (K _d)		Sandstone
					Shaftesbury (K _{sh})		Shale
					Pelican (K _{pl})		Sandstone
					Joli Fou (K _j)		Shale
		Lower	/	Mannville	Grand Rapids (K _g)		Lithic sand and sandstone
					Clearwater (K _c)		Shale and siltstone
					McMurray (K _m)	Wabiskaw	Glaucconitic sand and silt
						Upper	Nearshore marine sands and black clays
						Middle	Estuarine fine sands and gray clay with some oil impregnation
					Lower	Continental pond (lacustrine) clays	
						Oil impregnated sands	
					Erosional Unconformity		

Figure 4-2. Regional stratigraphic column of the Mesozoic and Cenozoic eras (adapted from BOVAR 1996).

4.3.2 Oil sand mining

Oil sand mines are open pit mines currently dominated by truck and shovel operations. The oil sand is confined to the lower McMurray formation (see Figure 4-2) and overlying OB materials must be removed to gain access to the formation. OB materials are classified into three basic categories: 1) saline/sodic OB, 2) non-saline/non-sodic OB, and 3) reclamation material.

4.3.2.1 Reclamation material salvage

Reclamation material salvage is the first step in oil sand mining. Reclamation materials are technically a component of the non-saline/non-sodic OB and are generally salvaged from the Pleistocene and Holocene deposits (see Figure 4-2). Different materials and salvaging practices result in different types of reclamation materials. The peat are recent (Holocene) deposits and are often mixed with the underlying mineral material creating a peat/mineral mix, henceforth denoted simply as H_o. The mineral materials salvaged for use in reclamation are generally Pleistocene deposits. Properties, including clay content, pH, SAR and hydrocarbon content of the Pleistocene materials can vary greatly depending on the depositional framework. Pleistocene-lacustrine (P_l) material is generally high in clay content and can have higher than desirable pH. Undifferentiated Pleistocene till (P_g) is also often high in pH and may contain hydrocarbons and is usually a sandy loam. Pleistocene-fluvial (P_f) is characterized by a sandier texture and can contain gravel. When used as reclamation material, the fluvial material is often mixed with the overlying peat to alleviate the textural problems (Earl Anderson, personal communication). The depth to which reclamation material is salvaged is dependent on the quality and suitability of the material as a plant growth medium.

4.3.2.2 Overburden removal

Reclamation salvage is followed by OB removal accomplished using truck and shovel operations. OB materials are highly variable and stored in large above-ground storage facilities (or dumps) according to chemistry (saline/sodic versus non-saline/non-sodic).

Saline-sodic OB materials are associated with the marine shales of the Clearwater formation (see Figure 4-2) and are plagued with high clay content, residual hydrocarbons, salinity and sodicity. The Clearwater formation is a clay-dominated formation, prone to shrinking and swelling, which poses some unique structure stability challenges in addition to revegetation challenges associated with high salinity. Although saline-sodic OB will make up a large proportion of the reclaimed structures in the AOSR, it has not been included in this study as an attempt to minimize variability.

The non-saline/non-sodic OB material is plagued with high clay content, high pH, high salinity and/or residual hydrocarbons. The non-saline/non-sodic OBs considered in this study (Syncrude) are materials that are neither saline/sodic nor suitable as reclamation materials. This could be due to physical limitations, for example high clay or sand content or high percent stones, or chemical problems for example high pH or high residual hydrocarbon (HC) content. These

materials require 1 m of capping with suitable reclamation material. At Suncor capping of their OB, limited predominantly by HCs, require only a 0.2 m cap, but are not considered in this study.

4.3.2.3 Reclamation material requirements

All oil sand mining operations are governed by legislative approvals. Reclaimed land is required to have a land capability classification (according to the LCCS, Leskiw 1998) of at least a Class 3 without regard for individual test limits. The LCCS produces a capability rating based on a wide range of soil properties including physical and chemical properties. Specific requirements as outlined in Table 8 from the Alberta Soils Advisory Committee (Macyk et al. 1987) for “Fair” or better (Table 4-1), however, are applied to the top 0.20 m of the reclaimed profile (Earl Anderson, personal communication).

Table 4-1. Alberta Soils Advisory Committee requirements for top-soil (0-20cm) amendments for reclaimed soils in the Athabasca Oil Sand Region (Macyk et al. 1987).

Parameter	Requirement
pH	< 7.5
E.C. (dS/m) [†]	< 4.0
SAR [‡]	< 8.0
Unacceptable textures [§]	Clay, Heavy Clay, Sand, Loamy Sand

[†] Electrical Conductivity

[‡] Sodium Adsorption Ratio

[§] Soil textural classes as per SCWG (1998)

Salvage of peat and mineral material together at a 40-70% peat to mineral volume ratio and directly placed on the area to be reclaimed is termed direct placement (DP) material (Figure 4-3). It is a one-lift salvage and placement procedure. When peat/mineral mixes (H₀) are salvaged, the volume ratio of peat to mineral is much higher and this material is strictly used as a surface amendment. When mineral materials are discretely salvaged (i.e. no organic component) it is called secondary material (2°) material. Alone it would not meet the reclamation requirements outlined in Table 4-1 and is therefore amended with the H₀ material resulting in a two-lift salvage and placement procedure.

4.3.2.4 Ore removal, bitumen extraction and tailings sand production

Once the OB is removed, oil sand is recovered using truck and shovel operations to a depth determined by the ratio of total volume of OB handled to bitumen volume recoverable (12 or less) and transported to the extraction plant by truck or hydrotransport (hot water slurry) for bitumen extraction. Bitumen is extracted using the Clark process (after Karl Adolph Clark), which is a hot water assisted NaOH extraction (Creighton 1972). The tailings sand (TSS) by-product of the extraction process is hydraulically transported (using a piping network) as a slurry to designated

sand storage facilities to undergo natural dewatering and await capping with reclamation material to a depth of 0.35 m (0.5 m historically) at Syncrude and 0.20 m at Suncor.

The initiation of sand dykes for containment of tailings slurry containment sparked research into the use of local soil amendments as a cover, or cap, for the tailings sand material. Aside from chemical and nutritional problems, the tailings sand is extremely susceptible to wind and water erosion if left in piles.

Massey (1972) and Berry and Klym (1974) first evaluated overburden clay and muskeg as surface amendments to tailings sand with the primary objective being sand stabilization. Research followed which characterized the TSS as having high hydraulic conductivity and low moisture retention, high sand content (around 97% sand), high pH, low CEC dominated by sodium, low organic matter content, negligible amounts of available or extractable amounts of the three major plant nutrients N, P and K and exhibiting hydrophobicity upon drying (Massey 1972; Berry and Klym 1974; Takyi et al. 1977; McGill et al. 1980; Macyk and Turchenek 1995). Lesko (1974) reported that the high pH (reaching 9.5) decreased to near neutral and even slightly acid two years after placement. Subsequent work with TSS showed that neither pH nor salinity is limiting (Takyi et al. 1977; Logan 1978; McGill et al. 1980; Macyk and Turchenek 1995).

4.3.2.5 Reclamation practices and prescriptions

Reclamation is progressive meaning that materials are salvaged from a pre-mining area and immediately transported to a designated reclamation TSS or OB storage facility. Both reclamation salvage and placement are performed during the winter when the soil is frozen to provide safe access and minimize soil compaction. Figure 4-3 summarizes the materials management. In the summer following material placement, the reclamation areas are worked with a variety of heavy and agricultural equipment to break down the large blocks of mineral and/or peaty materials and improve soil tilth.

Four specific reclamation prescriptions were evaluated in this study (Figure 4-4). The two TSS prescriptions are designated 'Coarse' sites (sand dominated) while the two OB prescriptions are designated 'Fine' sites (clay dominated). Prescriptions were selected largely based on their relevance to past, current and future reclamation practices.

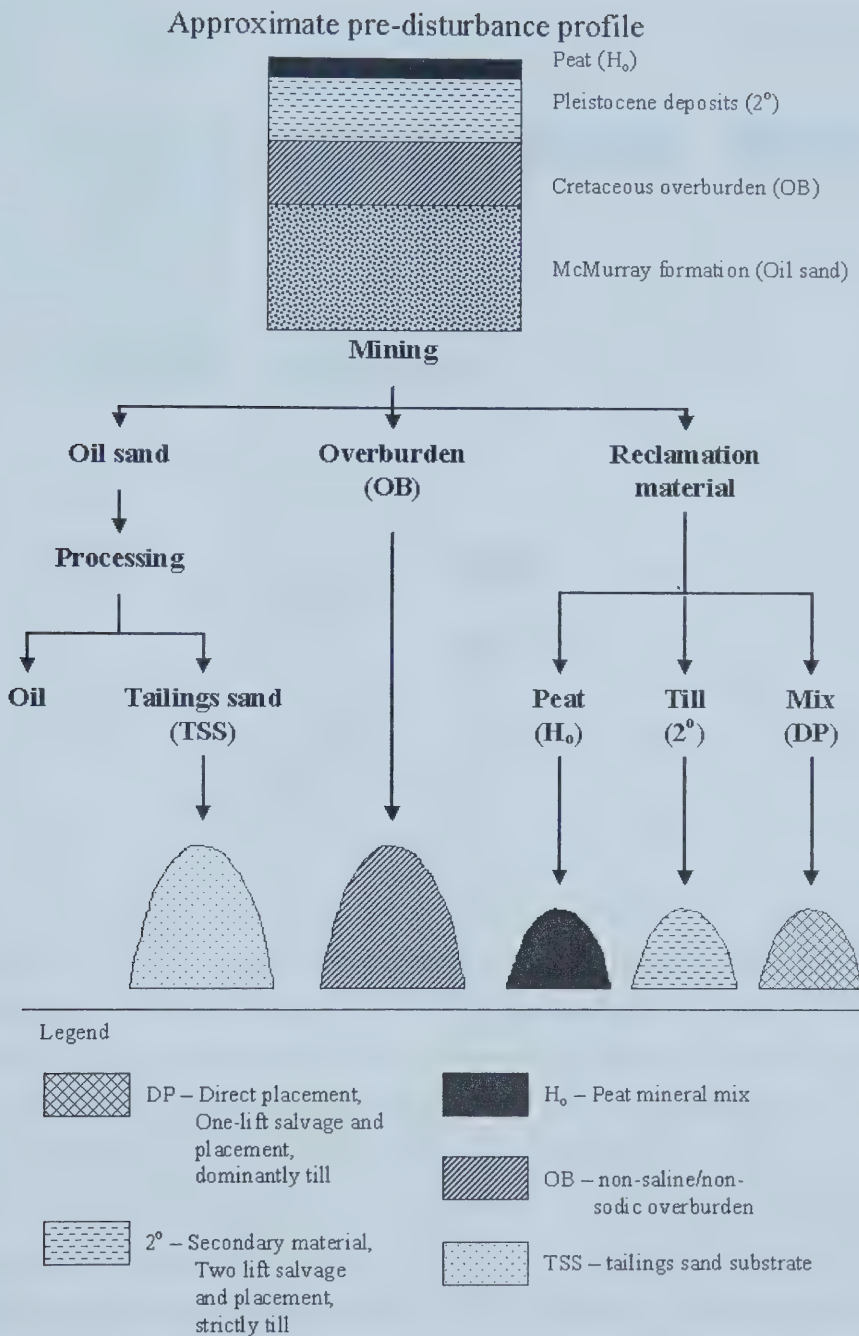


Figure 4-3. Schematic representation of the mining and material salvage process with respect to materials requiring capping (OB and TSS) and materials available for reclamation (peat [H₀], till [2°] and a mixture of peat and till [DP]) considered in this study.

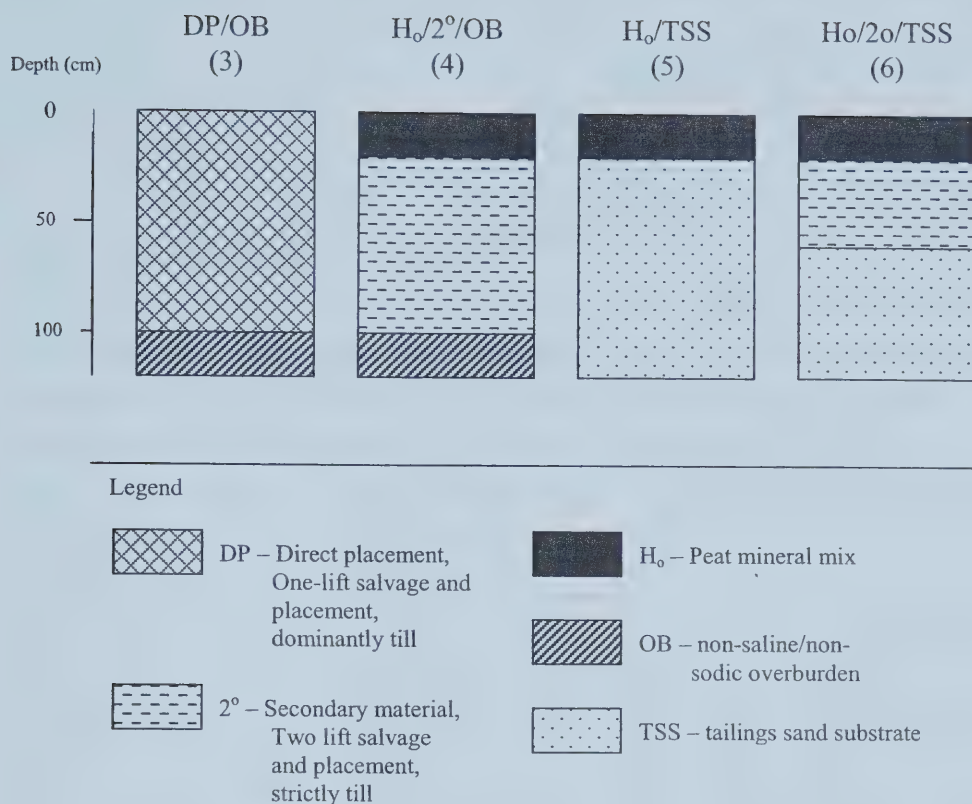


Figure 4-4. Reclamation prescriptions investigated.

Prescriptions 3, 4 and 6 in Figure 4-4 were selected because they will be dominant prescriptions at the Mildred Lake Mine site (Syncrude Canada Ltd.). Prescription 5 was located on the Suncor Mine site and was selected because it is more typical of the reclamation prescriptions used in newer developments to the north where fine textured reclamation material is limited. Note that Figure 4-3 and Figure 4-4 are generalizations for the purpose of this study and are not intended to be comprehensive of all substrates, reclamation materials, practices or prescriptions in the AOSR. These prescriptions correspond to soil units F, E, H and A of Leskiw and Moskal (1997a). In 1997 (Leskiw and Moskal 1997a,b) prescriptions 3, 4 and 6 accounted for 72% of Syncrude's reclamation and prescription 5 alone accounted for 34% of Suncor's reclamation (Table 4-2).

Table 4-2. Extent of reclaimed soil prescriptions at the Syncrude Mildred Lake mine and the Suncor mine in 1997 (Leskiw and Moskal 1997a,b).

Prescription	Soil unit	Materials	Mine	Total (ha)	Extent (ha)	%
3	F	DP/OB	Syncrude	1004	72	7
4	E	H ₀ /2°/OB	Syncrude	1004	175	18
5	H	H ₀ /TSS	Suncor	554	186	34
6	A	H ₀ /2°/TSS	Syncrude	1004	473	47

4.3.2.6 Revegetation and fertilization

In the spring of the first year after placement, Barley (*Hordeum vulgare* L.) is planted as a nurse crop primarily to prevent erosion on reclaimed areas at both Syncrude and Suncor. At Syncrude, sites are fertilized once to provide available nutrients for the barley crop (Earl Anderson, personal communication). Suncor fertilizes their TSS sites for the first five years after reclamation (Leo Paquin, personal communication). Total fertilizer inputs were approximated based on the blends and application rates at both Syncrude and Suncor (Table 4-3)

Table 4-3. Fertilizer inputs to reclamation prescriptions.

Site	Year(s)	Blend				Rate (kg ha ⁻¹)	Total added (kg ha ⁻¹)			
		N	P ₂ O ₅	K ₂ O	S		N	P	K	S
Syncrude	1	10	30	15	4	350	35	46	44	14
Suncor	1	23.5	25	8	-	300	71	33	20	0
Suncor	2-5	31.5	16	5	-	250	315	70	41	0
Suncor	1-5	Total					386	103	61	0

Suncor plants selected tree species into the barley crop the year that it is seeded, whereas Syncrude plants trees the following growing season. Planted tree species are dominantly trembling aspen (*Populus tremuloides*), white spruce (*Picea glauca*), and jackpine (*Pinus banksiana*) and to a lesser extent paper birch (*Betula papyrifera*). Even black spruce (*Picea marianna*) has been planted at Syncrude in the past, although it is not a current practice. Shrub species include green alder (*Alnus crispa*), red-osier dogwood (*Cornus stolonifera*), Canada buffaloberry (*Shepherdia canadensis*), pincherry (*Prunus pensylvanica*) and Saskatoon berry (*Amelanchier alnifolia*). Syncrude has also successfully planted low bush cranberry (*Viburnum edule*) and Suncor is planning to initiate this species in the summer of 2002 (Earl Anderson; Leo Paquin, personal communication). Forest management regulations stipulate an 80 km radius for collection of all propagation material (seed or vegetative). Further revegetation of sites occurs through propagules in the reclamation materials and invasion from surrounding ecosystems.

4.4 Methods

4.4.1 Statistical design and analysis

4.4.1.1 Experimental design

Natural analogues were selected for comparison (Chapter 3) with the four prescriptions in Figure 4-4. Sand dominated soils (Coarse) and clay dominated (Fine) natural analogues were selected for this comparison. The resulting experimental design consists of three levels: site *type* (natural and reclaimed), site *texture* (coarse and fine), and site *prescription* (1-6). The study included 44 sites: 20 natural and 24 reclaimed. The site *type* and *texture* create a two-way classification. *Texture* (fine or coarse) is crossed within *type*, and *prescription* is nested in texture assigning the two natural sites *prescription* labels of 1 and 2 and the reclaimed sites 2 through 6 (Figure 4-5).

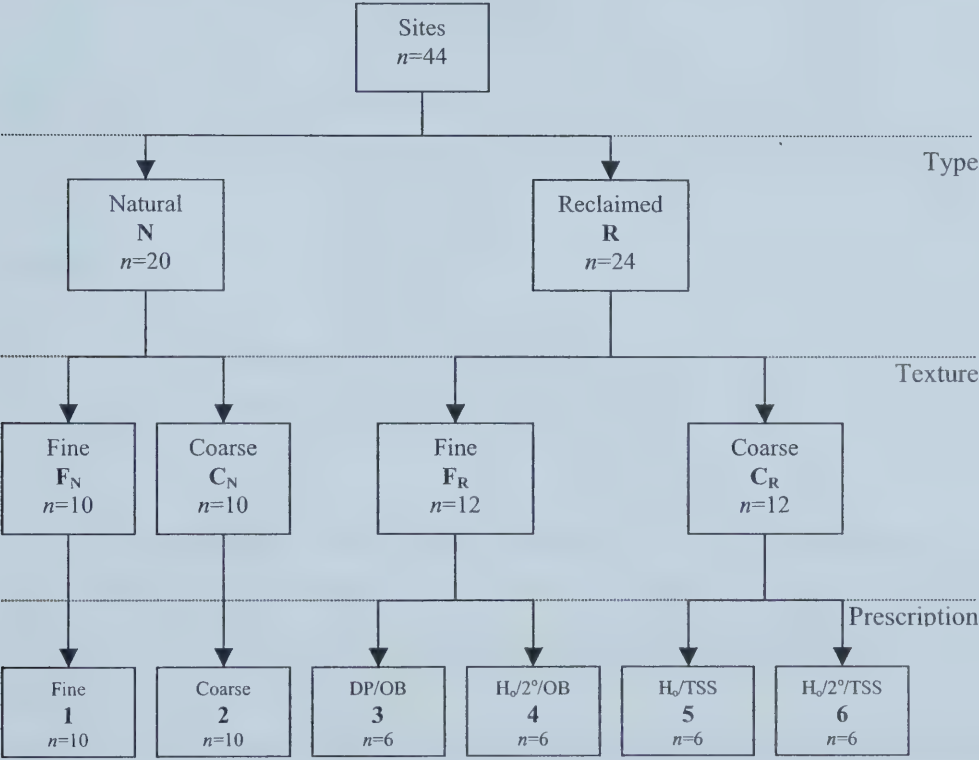


Figure 4-5. Experiment design structure (symbols defined in Figure 4-3).

4.4.1.2 Pre-planned comparisons

Selected pre-planned comparisons were used to control overall experiment wise error (Table 4-4). The Tukey multiple comparison test (see Steel et al. 1997) was used with an error rate of $\alpha = 0.05$ applied to the family of all paired comparisons.

The Tukey multiple comparison test was performed on all data. A statistical difference is assigned by the Tukey multiple comparisons only if significant treatment effects are detected by the analysis of variance. Otherwise, the Tukey results are viewed as merely suggestive of possible differences.

Table 4-4. Selected pre-planned comparisons between treatments.

Comparison	Symbol (Figure 4-5)
Natural <i>versus</i> reclaimed	N <i>vs.</i> R
Natural\fine <i>versus</i> reclaimed\fine	F _N <i>vs.</i> F _R
Natural\coarse <i>versus</i> reclaimed\coarse	C _N <i>vs.</i> C _R
Natural\fine <i>versus</i> reclaimed\fine\DP/OB	1 <i>vs.</i> 3
Natural\fine <i>versus</i> reclaimed\fine\H ₀ /2°/OB	1 <i>vs.</i> 4
Natural\coarse <i>versus</i> reclaimed\coarse\H ₀ /TSS	2 <i>vs.</i> 5
Natural\coarse <i>versus</i> reclaimed\coarse\H ₀ /2°/TSS	2 <i>vs.</i> 6
DP/OB <i>versus</i> H ₀ /2°/OB	3 <i>vs.</i> 4
H ₀ /TSS <i>versus</i> H ₀ /2°/TSS	5 <i>vs.</i> 6

4.4.1.3 Statistical model

The statistical model based on the design structure in Figure 4-5 is outlined in Equation 4-1.

Equation 4-1. $y = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \chi(\alpha\beta)_{k(ij)} + e_{ijkl}$

Where:

- α_i = type
- β_j = texture
- $\alpha\beta_{ij}$ = interaction between type and texture
- χ_k = prescription
- e_{ijkl} = natural error

An interaction term between type and texture was included because it is reasonable to expect that these variables are dependent such that the simple effects of texture may be dependent on type. This would be observed if the direction or magnitude of response to texture differed between types.

Because the nested term, prescription, is a fixed variable the model and fixed effect model and the appropriate error term for analysis is the natural error. Performing this analysis returned as significant interaction ($\alpha = 0.05$) for nearly all comparisons making it difficult to interpret differences between the main effects of the model. Using the nested term (prescription) to test the main effects and interaction terms is more conservative and therefore returns a significant result less often, but provides increased confidence in the analysis for the main effects and simplifies interpretation of results..

4.4.1.4 Test for normality

Analysis using the general linear model (GLM) is appropriately applied only to data that are normally distributed. Tests of normality were performed on all required variables using **proc univariate normal plot** in SAS (1999) using the Shapiro-Wilk w (see Steel et al. 1997) statistic and corresponding P -value. Tests were performed on residuals for amounts of nutrients to 1 m depth (i.e. Mg ha^{-1} or kg ha^{-1}), Ln transformed proportions of nutrients held in the top 0.20 m of profiles and Ln transformed selected nutrient ratios. Residuals were calculated for each observation according to Equation 4-2.

Equation 4-2.

$$\text{Residual} = \text{Observation} - \text{mean}$$

Normally distributed data are those for which the Shapiro-Wilk w statistic returns a P -value less than alpha (0.05). Near normally distributed data are those for which the Shapiro-Wilk w statistic returns a P -value is less than alpha (0.05) after 1-4 clear 'outliers' were removed from the data set (total $n = 44$). 'Outliers' are values that were clearly deviating from the normal distribution. These were removed only from the sample to determine if normality was limited by their presence. They remained in the data used for the analysis of variance causing conclusions based on the analysis to be conservative (Lindman 1974).

Non-normally distributed data are those that did not conform to a normal distribution after the removal of 'outliers' (as described above). These data include P_a and N_a to 1m depth. Soil pH is also has non-normal distribution, but no clear 'outliers' could be removed from the data-set to test for 'near-normality' as described above. The analysis of variance was used to analyze the data and caution was used in the interpretation of P_a and N_a statistics.

4.4.2 Site selection

Attempts were made to find suitable plots (natural and reclaimed) within the existing plot network in the AOSR and to integrate plots where possible with current research (Appendix A). Where suitable existing plots could not be located for this study, new plots were established. Natural sites were selected primarily on the basis of texture of parent material and reclaimed sites were selected to be representative of their associated prescription. The natural soils in the study area are of similar age and climate and were all upland, well to moderately well drained sites. As part of the reclamation and revegetation program conducted by the Reclamation Department in the Mine Operations at Syncrude, permanent 20×20 m vegetation monitoring plots are established each year on reclaimed planted areas. At Suncor, transects are set up on the reclaimed material and monitored for soil chemistry and vegetation. For this study, all reclaimed

sites were established within ~10m of a Syncrude monitoring plot or a Suncor monitoring transect. The age of the reclaimed soils (with respect to year of reclamation) varied from 1990 to 2000 at Syncrude, and from 1972 to 1996 at Suncor. All reclaimed soils were well drained.

4.4.3 Plot establishment

In early June of 2001, 40 m transects were established for the burial of ion exchange resin (IER) bags (Chapter 2) for incubation during the summer. Transects were marked at 10 m spacing with a soil investigation pit at the center of each. GPS coordinates were taken at each end of each transect to record location accurately.

4.4.4 Sample and data collection

4.4.4.1 Soil morphology

All soils were investigated to a depth of 1 meter in the center of each transect. Soil profile descriptions were made for classification using the Canadian System of Soil Classification (SCWG 1998) according to the Canadian Soil Information System (CanSIS) Manual (Day 1983) for the natural sites. Reclaimed profiles were described for classification according to Land Capability Classification for Forest Ecosystems in the Oil Sands Region (LCCS) (Leskiw 1998). Detailed soil profile descriptions can be found in Appendix D.

4.4.4.2 Soil sampling and preparation

Soil sample and bulk density samples were collected by horizon, and stored in sealed plastic bags. At the end of each day, chemical samples were air dried in tin pans in a dry empty greenhouse and subsequently ground to pass a 2mm sieve drum and weight roller at the Ellerslie Research Farm (University of Alberta, Edmonton, Alberta). Moisture content and bulk density were performed on mineral and organic horizons according to Kalra and Maynard (1991).

4.4.4.3 Chemical analyses

Soil pH was determined on saturated paste extracts, and in water (2:1) and CaCl_2 according to McKeague (1978). For the highly organic materials (LFH) ratios had to be increased to 10:1 and performed only using the water method. EC was also determined on the saturated paste extracts according to McKeague (1978). CEC and TEC (Ca, Mg, Na and K) were determined in NH_4OAc at pH 7 according to Chapman (1965) using a Perkin-Elmer Atomic Absorption Spectrophotometer (AAS). Ca, Mg and Na concentrations were also determined using the AAS on the saturated paste extracts for the calculation of the sodium adsorption ratio (SAR). Total and available P, total and available N, total and organic P and C were determined as described in Chapter 3.

4.4.4.4 Physical analyses

Particle size was determined by the hydrometer method following pre-treatment for carbonates and organic matter where necessary according to Sheldrick and Wang (1993). Particle size separates (2000 – 53 μm and <53 μm) were obtained using an Allen Bradley sonic sifter separator that uses an oscillating air column for dry particle size separation. Samples were ground gently until aggregates could not be seen with the naked eye. Pulse and amplitude settings were both set at one and one gram samples were oscillated for 5 minutes. If aggregates remained in the sieve nest, they were reground and oscillated until less than one percent of original sample was found in the <53 μm fraction. For more information on the uses, capabilities and limitations of sieves, see ASTM (1985) and Anonymous (2000) and for more information on the principles of the oscillating air column as a method for particle size separation see Anonymous (1995), Ward (1993), Kaye (1999) and Allen (1981).

4.4.4.5 Ecosite classification

Species present were identified in a 5.64 m radius plot centered on the soil investigation pit (see Figure 2-3, Chapter 2). All vegetation occurring in the plot was recorded and ecosite classification was estimated. Procedures outlined in Beckingham and Archibald (1996) were not followed strictly. Plots used had the same area (100 m²) but were circular rather than square. Classification was done in the field based on dominant species by ocular estimate, but percent cover data were not recorded. Species found in natural plots are listed in Appendix E.

4.4.4.6 Stand age and site index

Volume estimation parameters including basal diameter (BD), diameter breast height (DBH), and height of all trees greater than 1.5 m tall were collected on all trees in the circular plot. Volume estimates could be made in the future, if desired with data in Appendix E.

Cores were obtained by an increment borer on the tallest tree in each plot by species present. Cores were labeled, stored in plastic straws, frozen and subsequently aged in the lab with the assistance of light and dye. Site index at year 50 are estimated based on the age and diameter breast height (DBH) of the tallest tree, by species, in the radial plot established around the soil investigation pit and were determined using tables in Huang (1997) for trembling aspen, white spruce, balsam poplar and jackpine.

4.5 Results

4.5.1 Soil and vegetation classification

Based on soil and vegetation data collected (Appendix D and E) soil classification (CSSC)(SCWG 1998), land capability classification (LCC) (Leskiw 1998), ecosite phase (Beckingham and

Archibald 1996) and site index (Huang 1997) were determined and are presented in Table 4-5 for natural sites and in Table 4-6 for reclaimed sites. Ecosite classification and site index are not reported for reclaimed soils.

Natural fine textured sites are classified according to the CSSC as Orthic Gray Luvisols (OGL) with the exception of PSP 164 which is most accurately classified as a Solonetzic Gray Luvisol (SGL) based on the columnar structure of the B horizon (see soil profile description, APPENDIX D).

The vegetation is confined to the boreal mixedwood 'd' ecosite which is typical of moderately to fine textured till and glaciolacustrine materials in the region (Beckingham and Archibald 1996). Trembling aspen (*Populus tremuloides*) is present at all but one site with white spruce (*Picea glauca*) and balsam poplar (*Populus balsamifera*).

Natural coarse textured sites were generally classified as Eluviated Dystric Brunisols (EDB) and Eluviated Eutric Brunisols (EEB) depending on the pH of the upper B horizon. pH (H₂O) were reduced by 0.5 points as an approximation of the pH in CaCl₂ which is the common solution used for soil classification. There is variability in the depositional framework of these sites (Appendix D).

The LCC ranges from a class 2 down to a mode of 4M (moisture limitation based on available water holding capacity - AWHC). The corresponding ecosite classifications range from 'a', characterized by rapidly drained, moisture limited ecosystems to 'd', typical of finer-textured till or glaciolacustrine materials with b-ecosites as intermediates between the two. These sites are characterized by jackpine with some aspen and white spruce.

Fine textured reclaimed sites were generally class 2 – 3 according to the LCCS. Prescription 3, DP/OB sites have elevated pH throughout, but this limitation was offset by gains in AWHC due to the dominantly mineral material for the whole 1 m profile investigated. Class 3s and 4s in this prescription were limited by poor structure and low organic carbon content in the top 0.2 m of profiles. Prescription 4, H₀/2₀/OB was also limited by organic carbon content at the surface. The coarse textured reclaimed sites were generally class 3 according to the LCCS. Prescription 5, H₀/TSS was limited by AWHC and in some cases elevated pH in the lower subsoil and prescription 6, H₀/2₀/TSS was limited by elevated pH values throughout the profile.

The tree species present at the reclaimed sites are listed in Table 4-6. In themselves, the tree species do not reflect nutrient or moisture regime of the sites as in the natural sites, although the performance of the planted species over time would but is not in the scope of this study.

Table 4-5. Site locations, soil and vegetation classifications for natural sites.

ID	Location		Vegetation							
			Soil		Site index [£]					
	Prescription	N	W	Classification		Ecosite	Index [†]	Age [‡]	Species	
PGM				CSSC	LCC					
Natural – Fine										
PSP 141	1	56°56'31"	111°40'09"	L	OGL	2	BM d1.1	24	60	Aw
PSP 145	1	56°36'55"	111°20'30"	L	OGL	2	BM d3.3	15	nd	Sw
PSP 149	1	57°01'07"	111°55'36"	L	OGL	2	BM d1.5	23	40	Aw
PSP 164	1	57°17'06"	111°16'30"	Tk	SGL	2/3	BM d2.5	19, 23	55	Sw Aw
PSP 165	1	57°17'06"	111°16'30"	Tk	OGL	2/3	BM d2.4	7, 27	58	Sw Aw
PSP 173	1	57°08'34"	111°38'02"	L	OGL	2	BM d2.5	17, 17	93	Aw Sw
PSP 196	1	56°23'56"	111°25'40"	Tk	OGL	2	BM d1.4	18	nd	Aw
PSP 199	1	56°27'16"	111°11'07"	L	OGL	2	BM d1.8	19	nd	Aw
SV 4	1	56°57'11"	111°43'23"	L	OGL	2	BM d1.1	<6, 22	72	Pb Aw
SV 6	1	56°59'43"	111°43'30"	L	OGL	2	BM d3.1	15, 16	62	Sw, Pb
Natural – Coarse										
AUD 2	2	57°13'54"	111°28'25"	Fg	EEB	4M	BM a1.1	19	54	Pj
AUD 3	2	57°06'09"	111°38'13"	Fg	EEB	3	BM d1.9	16, 17	141	Aw Pj
AUD 4	2	56°58'08"	111°29'33"	Fg	EDB	3M	BM a1.3	14, 20	36	Aw Pj
PSP 161	2	57°12'52"	111°30'18"	Fg	GEB	3	BM a1.1	15	57	Pj
PSP 163	2	57°15'35"	111°21'11"	Fg	EDB	4M	BM a1.1	13, 16	149	Pj Aw
PSP 166	2	57°19'53"	111°12'39"	Fg	EDB	3	BM d1.1	15, 18	64	Sw Aw
PSP 171	2	57°30'17"	111°26'14"	Fg	EEB	4M	BM a1.1	13	nd	Pj
PSP 197	2	56°24'32"	111°11'31"	Fg	EDB	3/4	BM d1.4	20	nd	Aw
SV 2	2	57°00'20"	111°27'07"	V	EDB	2	BM b3.3	17, 23	55	Aw Sw
SV 10	2	57°04'25"	111°35'37"	Fg	EDB	4M	BM a1.1	18	38	Pj

£ where age was not determined (nd) site index was obtained from adjacent plots as part of the Soil and Vegetation Monitoring Plot network (see Appendix E)
† age applies to species in italics

‡ Site index at 50 years

PGM:

L = Dover glaciolacustrine clay and silt; Tk = Kinosia till; Fg = glaciofluvial outwash sand; V = erosional gullies and river valleys

EEB = Eluviated Eutric Brunisol; EDB = Eluviated Dystric Brunisol; ODB = Orthic Dystric Brunisol; GEB = Gleyed Eutric Brunisol; OGL = Orthic Gray Luvisol; SGL = Solonchic Gray Luvisol

M = available water holding capacity limitation; O = peaty surface limitation

LCC: Aw = trembling aspen (*Populus tremuloides*); Sw = white spruce (*Picea glauca*); Pb = balsam poplar (*Populus balsamifera*); Pj = jackpine (*Pinus banksiana*); Pj = lodgepole pine (*Pinus contorta*)

Table 4-6. Site locations, soil classification and tree species for reclaimed sites.

ID	Prescription	Location		Year reclaimed	Soil		Vegetation		
		N	W		PGM	Classification		Ecosite	Tree species
						CSSC	LCC		
Reclaimed – Fine									
90-1-5	3	56°59'44"	111°33'54"	1989	OB	-	2	-	Sw, Pb
90-2-1	3	56°59'40"	111°33'58"	1989	OB	-	2	-	Pj
90-2-2	3	56°59'30"	111°37'08"	1989	OB	-	2	-	Pj
90-2-3	3	56°59'29"	111°37'05"	1989	OB	-	4	-	Pj
92-1-7	3	57°00'06"	111°34'55"	1991	OB	-	-	-	Aw, Sw, Pb
92-1-8	3	56°59'43"	111°35'30"	1991	OB	-	3	-	Aw, Sw
93-2-2	4	56°59'49"	111°35'30"	1992	OB	-	2	-	Sw
94-2-21	4	56°59'59"	111°36'25"	1993	OB	-	2	-	Pj
94-2-23	4	57°00'07"	111°35'41"	1993	OB	-	3	-	Pj
94-2-26B	4	57°00'03"	111°36'16"	1993	OB	-	2	-	Pj, Pb
95-2-1	4	57°00'04"	111°34'28"	1994	OB	-	2	-	Aw, Pb
96-2-19	4	57°00'07"	111°34'56"	1995	OB	-	3O	-	Aw, Sw, Pj, Pb
Reclaimed – Coarse									
SUN 25	5	56°59'54"	111°27'38"	1972	TSS	-	3/4	-	Pj, Pl
SUN 29	5	56°59'54"	111°27'48"	1974	TSS	-	3	-	Pj, Pl
SUN 38	5	56°59'21"	111°29'02"	1985	TSS	-	5	-	Aw
SUN 61	5	56°58'54"	111°30'28"	1992	TSS	-	3	-	Pj
SUN 77	5	56°59'15"	111°31'47"	1996	TSS	-	3	-	Pl
SUN 78	5	56°58'41"	111°27'51"	1996	TSS	-	3	-	Pj
92-2-5	6	57°03'58"	111°39'48"	1991	TSS	-	3	-	Pj
94-2-13	6	57°06'07"	111°38'57"	1993	TSS	-	2	-	Aw
94-2-31	6	57°06'04"	111°38'56"	1993	TSS	-	2/3	-	Aw
96-2-16	6	57°03'53"	111°39'42"	1995	TSS	-	3	-	Aw, Sw
97-2-8	6	57°04'57"	111°40'15"	1996	TSS	-	3	-	Pj
00-02-06	6	57°05'53"	111°40'52"	1999	TSS	-	3	-	Aw, Sw

PGM: OB = overburden; TSS = tailings sand
LCC: M = available water holding capacity limitation; O = peaty surface limitation
Species: Aw = trembling aspen (*Populus tremuloides*); Sw = white spruce (*Picea glauca*); Pb = balsam poplar (*Populus balsamifera*); Pj = jackpine (*Pinus banksiana*); Pj = lodgepole pine (*Pinus contorta*)

4.5.2 Soil physical and chemical properties

4.5.2.1 Natural sites

TEC and CEC were determined on the composite samples associated with the IER bag burial sites and pH and EC were determined on the C horizons of the sites (Table 4-7). EC and pH are similar between the fine and coarse textured groups. TEC and CEC are higher in the fine textured group. The TEC are less than half of the CEC.

Table 4-7. TEC, CEC and pH of surface soil and EC of C horizon of natural sites.

Site	TEC [†]	CEC [‡]	pH [§]	E.C. [¶]
	(cmol ⁽⁺⁾ kg ⁻¹ soil)	(cmol ⁽⁺⁾ kg ⁻¹ soil)	H ₂ O	(dS m ⁻¹)
	Surface composite samples (LFH + Ae)			C horizon
Natural – Coarse				
AUD 2	4.7	10.5	5.3	0.179
AUD 3	5.7	20.5	5.1	0.054
AUD 4	4.3	20.5	4.7	0.052
PSP 161	5.9	16.3	5.1	0.065
PSP 163	1.8	6.5	4.9	0.057
PSP 166	9.0	26.5	5.0	0.163
PSP 171	3.5	16.3	5.1	0.146
PSP 197	2.5	8.0	4.7	0.065
SV 10	5.4	11.7	5.8	0.049
SV 2	11.8	29.0	5.4	0.065
$\overline{X}$	5.5	16.6	5.1	0.1
<i>S</i>	3.0	7.6	0.3	0.1
Natural – Fine				
PSP 141	15.3	29.2	5.7	1.138
PSP 145	7.3	15.7	5.1	0.228
PSP 149	9.6	22.8	5.2	0.098
PSP 164	15.5	41.7	4.9	0.179
PSP 173	27.1	45.4	5.6	0.195
PSP 196	9.5	20.6	5.3	0.146
PSP 199	6.4	14.4	5.4	0.049
SV 4	44.6	83.3	5.7	0.098
SV 6	33.2	80.4	5.2	0.179
$\overline{X}$	18.7	39.3	5.3	0.975
<i>S</i>	13.3	26.4	0.3	0.3

[†] total exchangeable cations Σ(Ca, Mg, K, and Na); [‡] cation exchange capacity; [§] pH (2:1 H₂O); [¶] electrical conductivity on saturated paste

$\overline{X}$ = sample mean; *S* = sample standard deviation

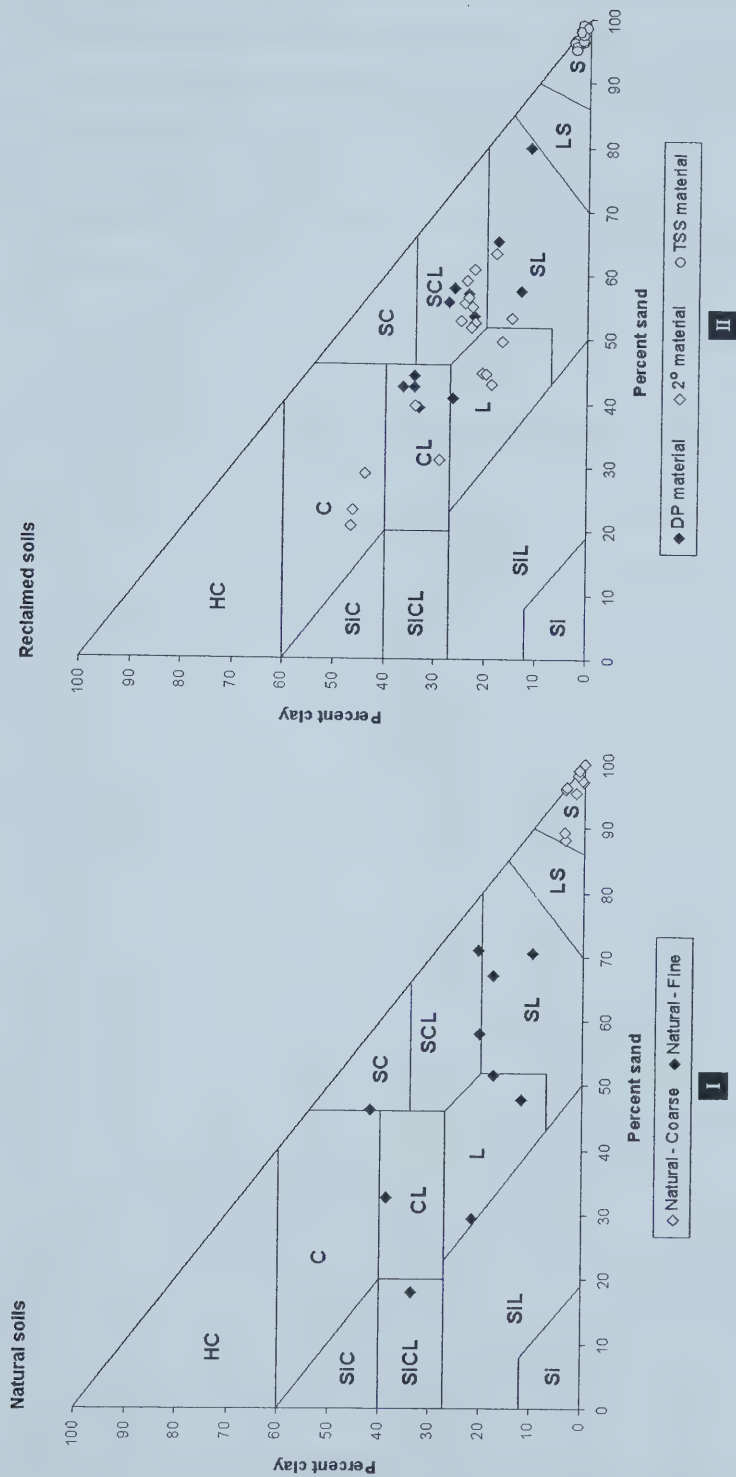


Figure 4-6. Soil textural class (according to the CSSC) of natural soil PGMs and reclamation materials (Textural triangle adapted from SCWG 1998).

The higher CEC and TEC in the fine versus the coarse textured soils were anticipated based on the textural differences between the sample groups. As Figure 4-6 illustrates, all coarse textured sites are dominated by material with less than 10% clay, and on average have 4.5%. On average, the PGM of the fine sites contain 23% clay.

4.5.2.2 Reclaimed sites

Physical and chemical properties of the reclaimed soils are presented in Table 4-8. The bulk density, pH and EC of the reclaimed soils are similar to the natural soils, except for some high bulk density values (>1.6 g cm⁻³) in the upper and lower subsoils of prescription 4 (H₀/2°/OB) and the upper subsoil of prescription 6 (H₀/2°/TSS).

Table 4-8. Select mean physical and chemical properties of reclaimed sites by horizon.

Layer	Parameter	Horizon thickness	w	Db	TEC	CEC	SAR	pH	E.C.
		(m)	(g g ⁻¹)	(Mg m ⁻³)	(cmol ^(c) kg ⁻¹ soil)		-	2:1 H ₂ O	(dS m ⁻¹)
DP/OB n = 6									
TS	$\overline{X}$	0.19	0.17	1.20	27.3	22.9	0.3	7.6	0.471
	s	0.07	0.07	0.21	7.7	11.0	0.2	0.3	0.038
US	$\overline{X}$		0.13	1.46	34.6	17.9	1.1	7.7	0.469
	s		0.05	0.32	5.4	9.2	0.3	0.5	0.070
LS	$\overline{X}$		0.15	1.41			1.1	7.5	0.460
	s		0.06	0.33			0.6	0.4	0.052
H ₀ /2°/TSS n = 6									
TS	$\overline{X}$	0.23	0.75	0.45	52.0	55.2	0.3	7.2	0.427
	s	0.13	0.19	0.18	19.8	23.1	0.2	0.5	0.063
US	$\overline{X}$	0.49	0.16	1.70	23.8	11.6	1.4	7.7	0.461
	s	0.06	0.04	0.13	7.4	5.6	0.8	0.2	0.026
LS	$\overline{X}$		0.15	1.68			1.6	7.5	0.450
	s		0.04	0.12			0.8	0.4	0.034
H ₀ /TSS n = 6									
TS	$\overline{X}$	0.18	0.09	1.14	23.4	21.1	0.1	6.7	0.318
	s	0.06	0.05	0.20	14.9	15.4	0.1	1.1	0.147
US	$\overline{X}$		0.04	1.48	6.6	4.9	0.2	7.3	0.350
	s		0.02	0.14	12.7	10.0	0.1	0.4	0.103
LS	$\overline{X}$		0.04	1.53			0.2	7.5	0.390
	s		0.01	0.07			0.1	0.5	0.115
H ₀ /2°/TSS n = 6									
TS	$\overline{X}$	0.15	0.33	0.82	41.5	37.2	0.4	7.6	0.471
	s	0.04	0.08	0.27	9.7	16.3	0.2	0.1	0.024
US	$\overline{X}$	0.85	0.15	1.62	28.3	12.8	2.1	7.8	0.478
	s	0.10	0.03	0.18	7.0	4.8	1.0	0.2	0.038
LS	$\overline{X}$		0.05	1.59			1.1	7.7	0.406
	s		0.04	0.09			0.5	0.2	0.064

Horizons according to LCCS (Leskiw 1998); in the field samples were collected primarily by discontinuities (Appendix D). TS = topsoil (0-20cm) or depth of organic; US = uppersubsoil (20-50cm) or depth of second lift; LS = lower subsoil (50-100cm); $\overline{X}$ = mean; s = standard deviation

The TEC and CEC values for reclaimed topsoil horizons are generally higher than the natural sites, perhaps due to the thick (~20cm) peat amendments at the surface except for the DP/OB treatment. The TEC of the reclaimed soils often exceeds the CEC where the opposite pattern is observed in the natural soils. This could be attributed to the greater amounts of mineral calcium (in the form of calcium carbonate) in the reclaimed soils compared to the natural being included in the TEC. Figure 4-6: II illustrates the distribution of reclaimed fine (DP and 2°) materials and reclaimed coarse (TSS) materials are similar to that found for the analogous natural sites (Figure 4-6:I).

4.5.3 Form and amounts of C, N and P to 1 m and 0.2 m depths

Table 4-9 provides a summary of the mean total amounts of selected forms of C, N and P to 0.2 and 1 m depths (including the LFH in the natural soils) for soils in this study along with standard deviation and the Tukey mean separation for the prescription level. Similar conclusions in regards to nutrient capital and availability are drawn using either assessment depth, 0.2 m versus 1 m (Table 4-9). For simplicity, the results from statistical analysis to 1 m depth are presented in detail in Figure 4-7 to Figure 4-11.

Figure 4-7 to Figure 4-11 are bar graphs with standard error bars plotted for the data to 1 m presented in Table 4-9 with the mean percent of the total amount being held in the top 0.20 m of the profiles with corresponding Tukey mean separation letters at the prescription level. Significant differences ($\alpha=0.05$) between treatments were detected for data to 1 m, data to 0.2 m and the proportions held in the top 0.2 m of the profiles for the model outlined in Equation 4-1 at the prescription level. Significant differences higher in the model (i.e. type or texture) may not be reflected at the prescription level and are noted where they occur in the text with the corresponding figure.

Table 4-9. Mean amounts of N, P and C to 1 m and 0.2 m depths by treatment group with standard error of the mean.

Type	Texture	Prescriptions	Statistic	Data to 0.2 m depth						Data to 1.0 m depth								
				Nitrogen		Phosphorus		Carbon		Nitrogen	Phosphorus		Carbon					
				N _{total}	N _{available} [†]	P _{total}	P _{available}	P _{organic}	C _{total}		P _{total}	P _{available}	P _{organic}	C _{total}				
Natural	Fine	FINE 1 (n=10)	$\bar{X}$	kg ha ⁻¹	kg ha ⁻¹	kg ha ⁻¹	kg ha ⁻¹	kg ha ⁻¹	kg ha ⁻¹	Mg ha ⁻¹	kg ha ⁻¹	Mg ha ⁻¹	Mg ha ⁻¹	Mg ha ⁻¹				
			$S_{\bar{Y}}$	3085ab	41.4a	736.5ab	37.2ab	507.4a	60.7b	60.1ab	4.0ab	74.0ab	1.9a	172.4bc	131.3bc			
	Coarse	COARSE 2 (n=10)	$\bar{X}$	364.3	7.4	106.5	7.8	72.0	7.4	7.3	0.6	10.2	0.4	11.9	0.3	20.2	8.4	
			$S_{\bar{Y}}$	991b	10.2b	407.4b	65.7a	247.4b	21.1b	20.0b	2.8bc	455.7a	1.1ab	82.0c	73.2c			
	Prescription	Fine	DP/OB 3 (n=6)	$\bar{X}$	868.8	5.6	82.3	1.4	83.4	15.5	15.6	3.9	12.6	1.1	6.2	0.4	79.5	81.6
				$S_{\bar{Y}}$	3150ab	16.9b	993.1a	10.2ab	257.7b	66.6b	59.1ab	5.7a	26.8b	1.3ab	433.7a	374.4a		
		H ₀ /2°/OB 4 (n=6)	$\bar{X}$	4323a	7.8b	370.9b	14.5ab	204.7b	92.4ab	87.1ab	11.7ab	32.7b	3.5b	55.7b	1.2ab	320.0ab	282.8ab	
			$S_{\bar{Y}}$	1008.5	1.1	66.1	6.3	18.7	20.2	20.0	2.7	2.5	0.3	13.8	0.1	60.4	58.3	
Coarse		H ₀ /TSS 5 (n=6)	$\bar{X}$	3283ab	9.2b	441.0b	26.3ab	219.1b	75.5ab	71.2ab	5.1bc	16.1b	0.9c	32.7b	0.6b	119.0c	111.6c	
			$S_{\bar{Y}}$	1020.8	1.1	90.9	6.8	27.0	23.4	22.4	1.0	0.7	0.1	7.1	0.1	19.9	18.6	
		H ₀ /2°/TSS 6 (n=6)	$\bar{X}$	5826a	8.5b	589.3b	6.1b	333.1ab	148.7a	127.0a	8.4bc	20.8b	2.1bc	17.7b	1.1ab	242.3bc	205.6abc	
			$S_{\bar{Y}}$	1270.8	0.5	70.4	1.4	56.8	43.1	33.9	1.0	1.4	0.1	3.2	0.2	46.8	36.3	

Note: the same subscripts indicate that the mean values are not significantly different.

Note: the same subscripts indicate that the mean values are not significantly different at the 0.05 level and do not apply across depth categories (1 m and 0.2 m)

$\bar{X}$ = sample mean; $S_{\bar{Y}}$ = standard error of the mean

[†] NO₃-N and NH₄-N

4.5.3.1 Total P

A significant difference ($P<0.0001$) was detected at the prescription level for P_t . The only significant difference detected by the Tukey mean separation procedure that can be attributed to the pre-planned comparison is the difference in P_t between the two fine textured reclamation prescriptions (Figure 4-7:III). The reclamation prescriptions have similar amounts of P_t to 1m depth as the natural analogues.

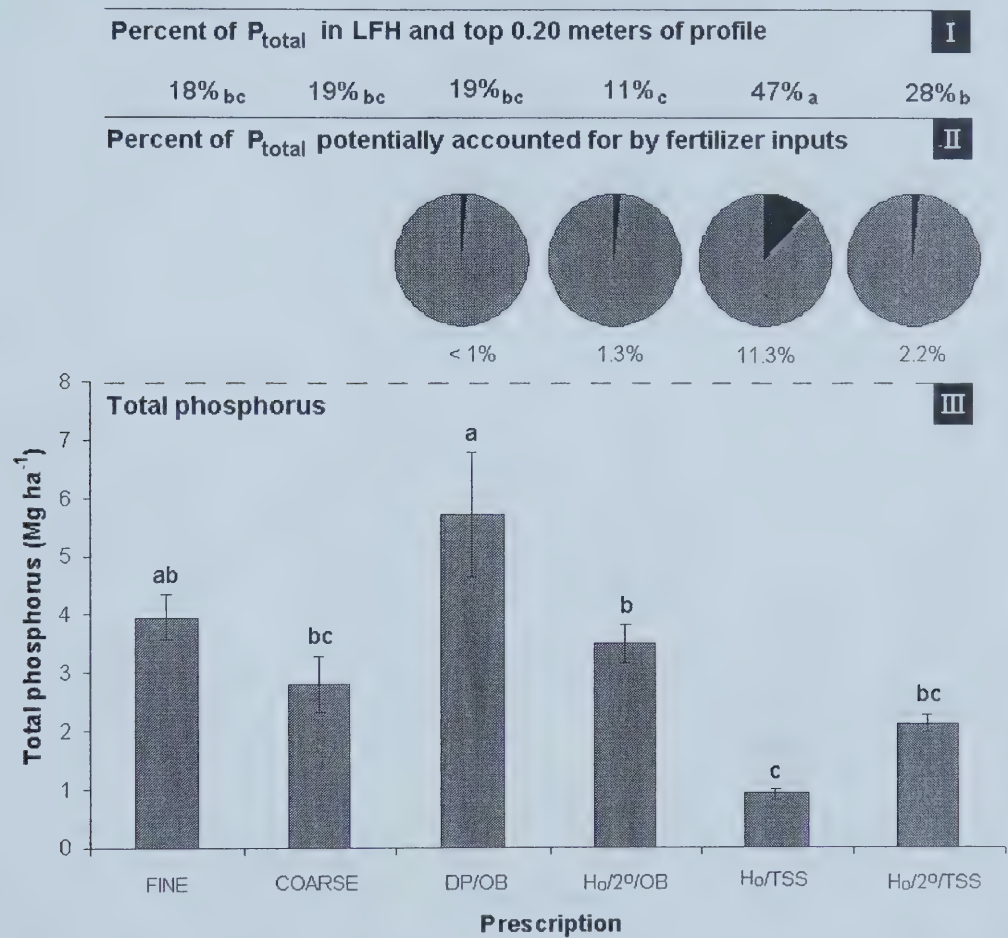


Figure 4-7. Mean total P content of treatments to 1 m depth, fertilizer contributions and proportions held in the LFH and top 0.2 m of profiles.

Recall from Table 4-3 that Suncor (prescription 5) adds about twice as much P_t compared to Syncrude (prescriptions 3, 4 and 6). Combined with the low total amount of P_t in the H₀/TSS prescription at Suncor this accounts for over 10% of the total P capital in the soil. Further, Figure

4-7 shows that prescription 5 (H₀/TSS) holds significantly more, approximately half, of the P_t to 1 m in the top 0.2 m of the profile.

4.5.3.2 Total N

Significant differences in N_t were found at the prescription level and can be attributed to the significantly higher amount of N_t in reclaimed prescription 3 compared to the fine natural analogues (Figure 4-8: III).

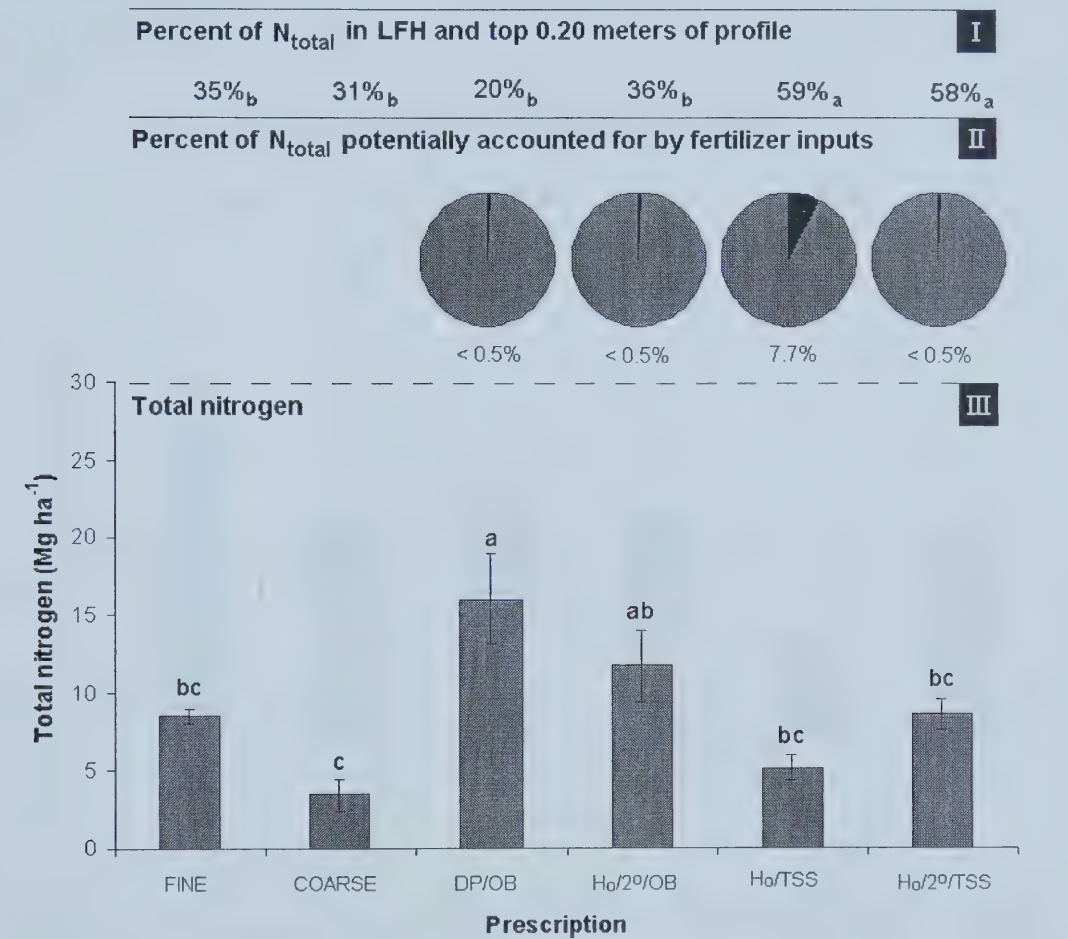


Figure 4-8. Mean total N of treatments to 1 m depth, fertilizer contributions and proportions held in the LFH and 0.2 m of profiles.

Similar to the P_t in Figure 4-7:II fertilization inputs of N to the H₀/TSS prescription account for a greater proportion (7.7%) of the total amount of nitrogen to 1 m compared to all other prescriptions, which are < 0.5% (Figure 4-8: II). The coarse textured reclaimed prescriptions (5 and 6) hold a significantly greater proportion of N_t at the surface than the natural soils or the fine

textured reclaimed soils (Figure 4-8: I) which can be partially attributed to the lower amounts of N_t to 1 m and the peat amendments at the surface.

4.5.3.3 Organic P

Significant differences in P_o were found at the prescription level ($P=0.0041$), but are not attributed to any of the pre-planned comparisons indicating that the reclaimed soils have similar amounts of P_o to 1 m (Figure 4-9:II). Similar to the trend in P_t , prescription 5 (H_o/TSS) has the lowest amount of P_o to 1m with a significantly greater proportion being held in the top 0.2 m of the soil profile (Figure 4-9:I).

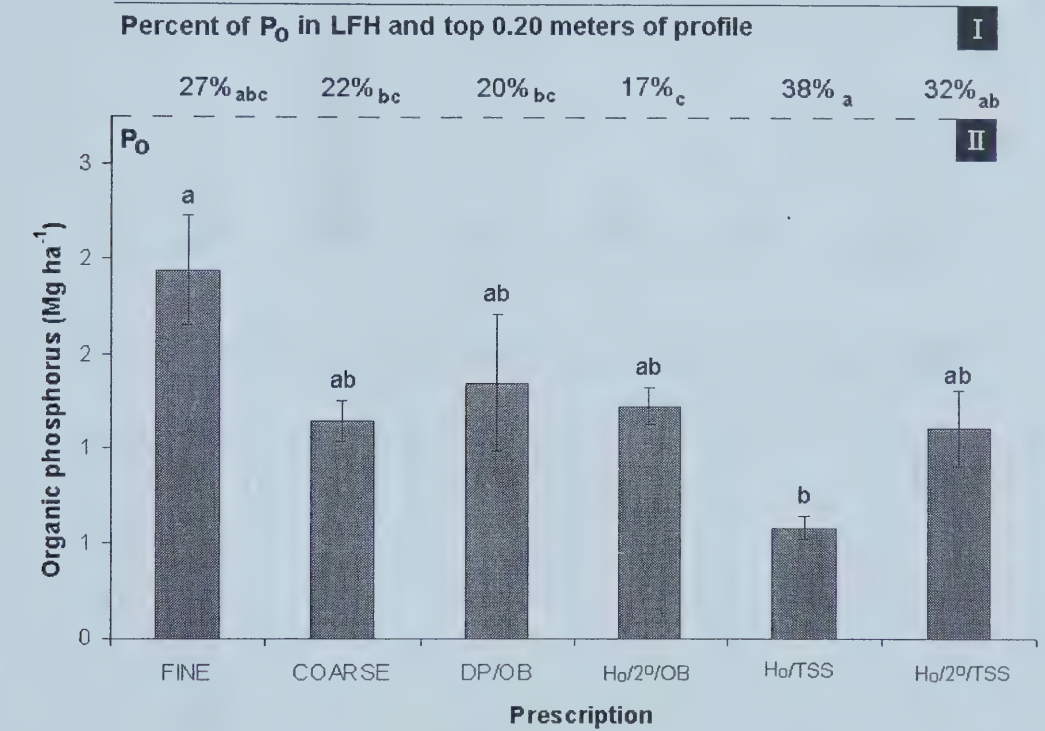


Figure 4-9. Mean P_o content of treatments to 1 m depth and proportions held in the LFH and 0.2m of profiles.

4.5.3.4 Available N and P

The statistical model was highly significant for both N_a ($P<0.0001$) and P_a ($P=0.0021$). With respect to P_a , there is a significant difference between the natural and reclaimed sites ($P=0.0027$), and between the fine and coarse textured sites ($P=0.0060$) and at the prescription level ($P=0.0021$) for data to 1 m. The significant interaction between the main effects ($P=0.0036$) indicates that the response to one main effect depends on the other (Steel et al. 1997).

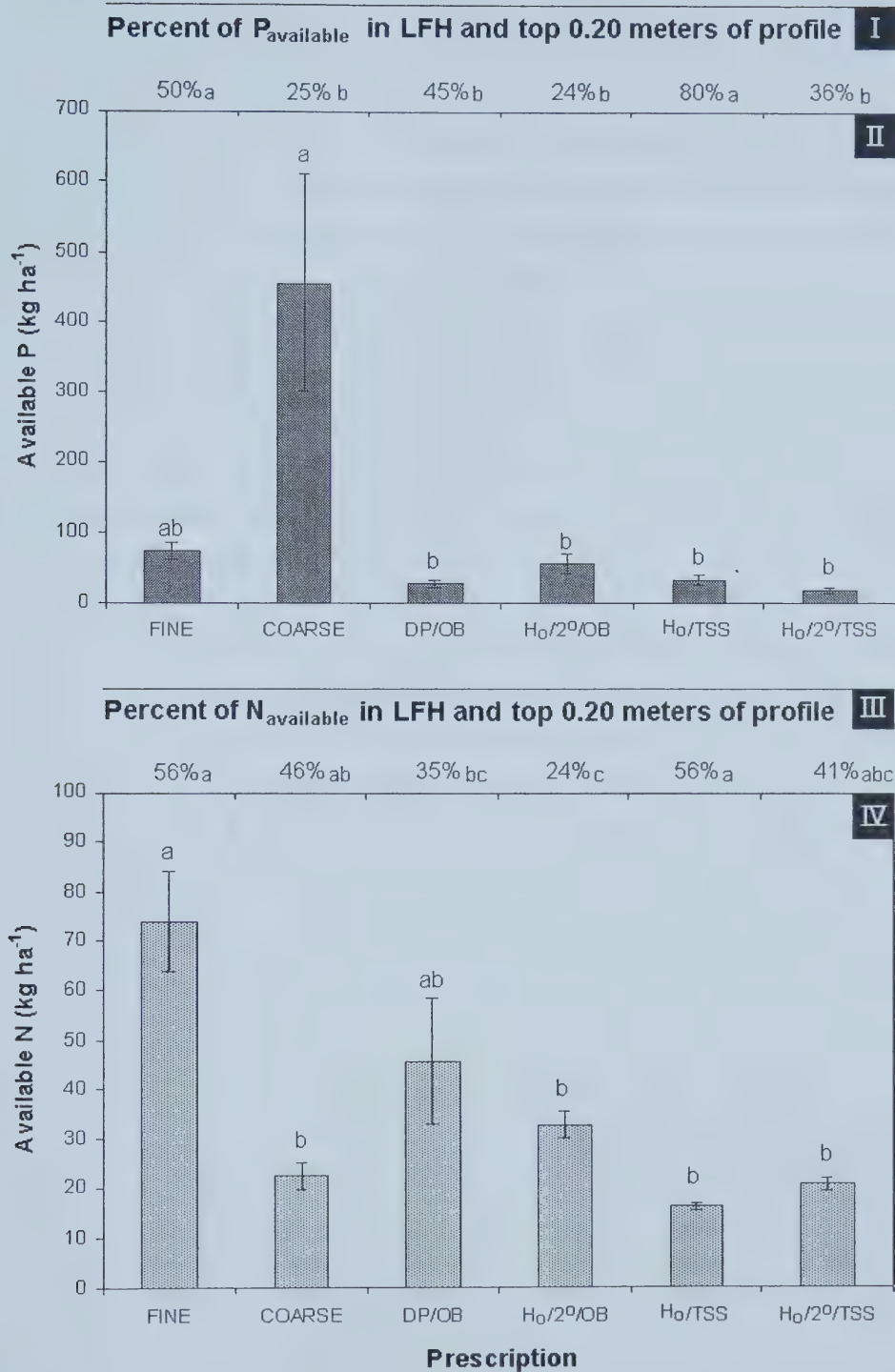


Figure 4-10. Mean P_a and N_a content of treatments and proportions held in the LFH and 0.2 m of profiles.

As Figure 4-10: II illustrates, the significant difference of both the main effects (natural vs. reclaimed and fine vs. coarse) can be attributed to the striking amount of P_a in the coarse textured natural sites, only one quarter being held in the top 0.2 m of the profile on average compared to half in the fine sites. The amount of P_a in the coarse textured reclaimed sites is lower than the fine, hence the interaction. Both TSS reclamation prescriptions (H_o/TSS and $H_o/2^\circ/TSS$) have significantly less P_a than the coarse natural analogues and the H_o/TSS prescription holds significantly more (80%) in the top 0.2 m of the profile than the coarse natural analogues. For N_a (Figure 4-10: III and IV), the difference is strictly at the texture level: fine textured sites have significantly more N_a to 1 m than do the coarse textured sites regardless of soil type (natural or reclaimed) ($P=0.022$). Significant differences at the treatment level ($P<0.0001$) can be attributed to prescription 4 ($H_o/2^\circ/OB$) which has significantly less N_a to 1 m than the fine natural analogues which hold significantly more N_a (56%) in the top 0.2 m of the profile. The coarse textured soils are all similar with respect to N_a .

4.5.3.5 Total and organic C

Figure 4-11:II is a stacked bar graph displaying total, organic and inorganic carbon in all treatments to 1 m. Significant differences were found at the prescription level ($P<0.0001$) for C_t to 1 m. Prescriptions 3 (DP/OB) and 6 ($H_o/2^\circ/TSS$) have significantly more C_t to 1 m than the fine and coarse natural analogues, respectively. No significant differences in C_o to 1 m were detected however, as Figure 4-11:I illustrates, the fine textured reclamation prescriptions hold significantly smaller proportion of C_o in the top 0.2 m of the profile than the fine natural analogues.

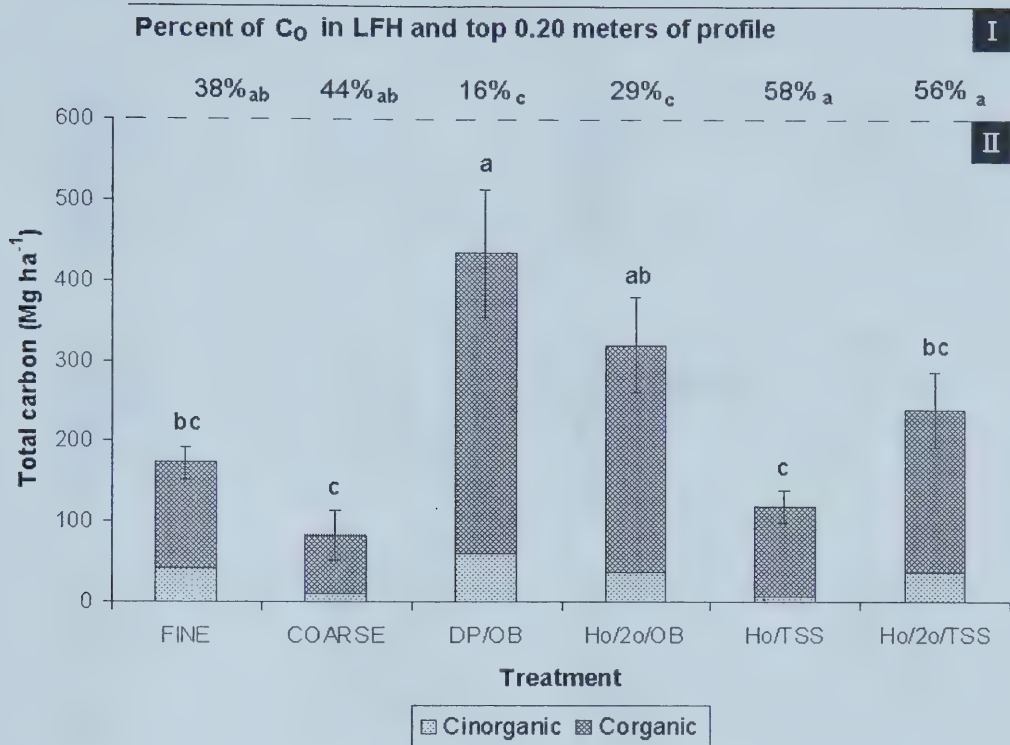


Figure 4-11. Stacked bar graph of mean C_o and C_i , adding to C_t by prescription and proportions of C_o held in the LFH and 0.2 m of profiles.

4.5.4 Phosphorus distribution with depth

4.5.4.1 Natural soils

The variability in the proportion of the various nutrients and their forms being held in the top 0.2 m of the soil profiles is indicative of variability in the distribution of these nutrients with depth as are data from Chapter 3.

Figure 4-12, Figure 4-13 and Figure 4-14 show the distribution of P_i (stacked amounts of P_i and P_o) and P_a with depth for the natural and reclaimed soils. Due to the substantial variability in the P distribution in the natural profiles, each individual profile was plotted separately (Figure 4-12 and Figure 4-13) while the reclaimed profiles are the average amount across the 6 replicates within each treatment (Figure 4-14).

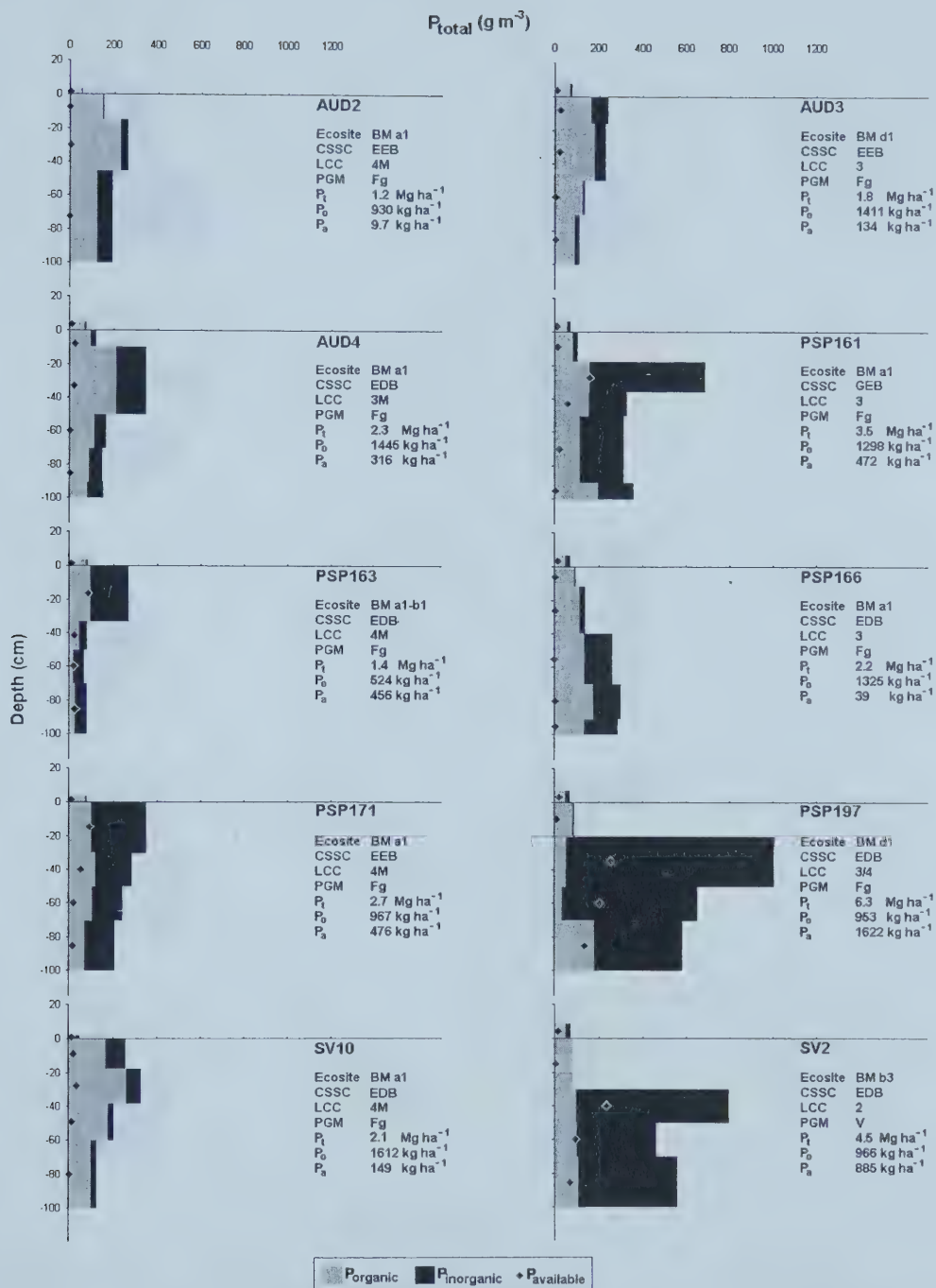


Figure 4-12. Stacked bar graphs of P profiles for natural coarse textured natural sites.

PGM: L = Dover glaciolacustrine clay and silt; Tk = Kinosis till; Fg = glaciofluvial outwash sand; V = erosional gullies and river valleys
 CSSC: EEB = Eluviated Eutric Brunisol; EDB = Eluviated Dystric Brunisol; ODB = Orthic Dystric Brunisol; GEB = Gleyed Eutric Brunisol; OGL = Orthic Gray Luvisol; SGL = Solonetzic Gray Luvisol

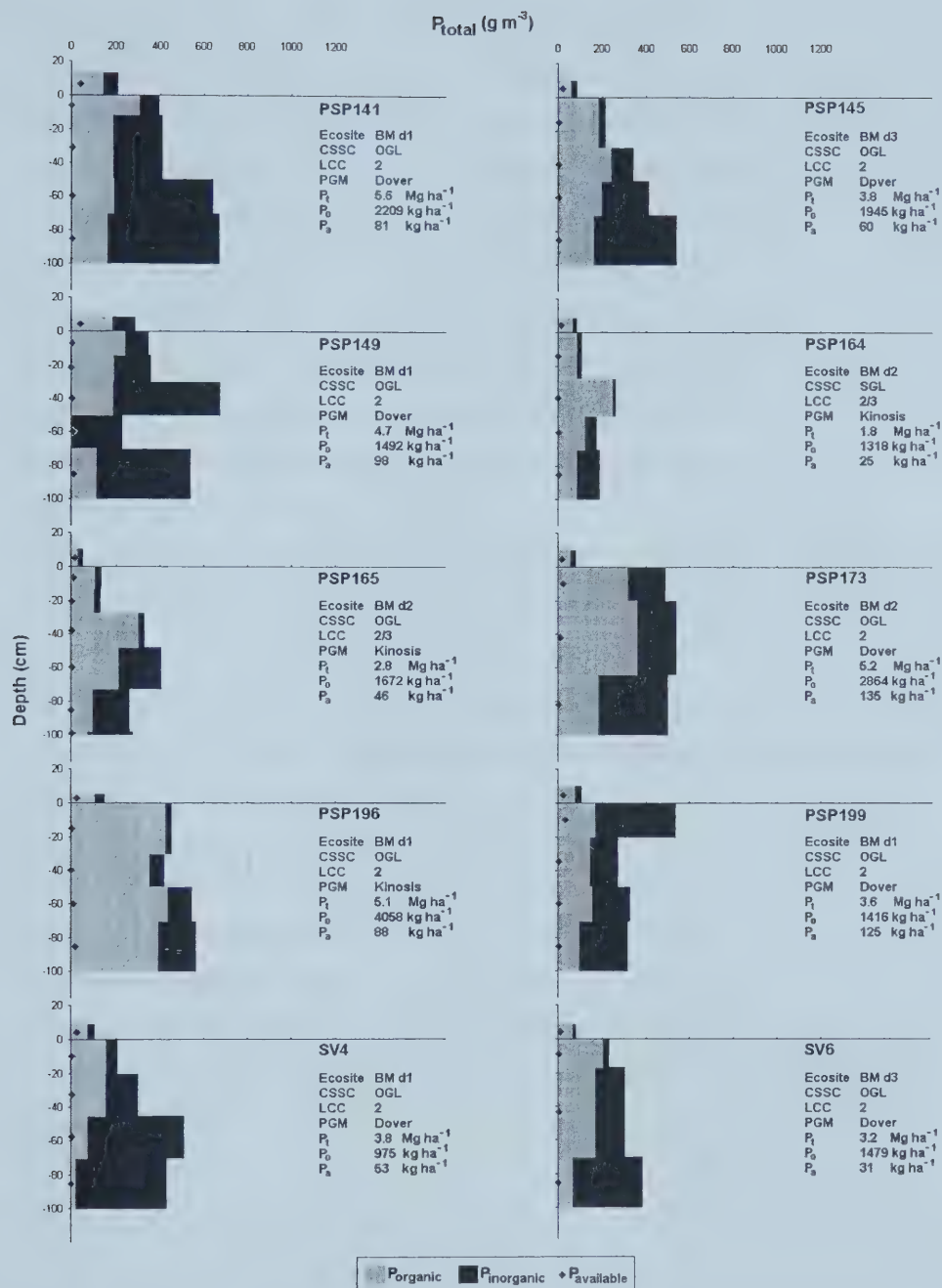


Figure 4-13. Stacked bar graphs of P profiles for natural fine textured natural sites.

PGM: L = Dover glaciolacustrine clay and silt; Tk = Kinosi till; Fg = glaciofluvial outwash sand; V = erosional gullies and river valleys
 CSSC: EEB = Eluviated Eutric Brunisol; EDB = Eluviated Dystric Brunisol, ODB = Orthic Dystric Brunisol; GEB = Gleyed Eutric Brunisol, OGL = Orthic Gray Luvisol; SGL = Solonchic Gray Luvisol

The P profiles of the fine and the coarse textured sites have no characteristic shape. Both treatments have considerable variability. For example, PSP 163 and PSP 197 (Figure 4-12) have large differences in total amounts of total P as well as the distribution. These profiles show evidence of P redistribution within the profile or depositional variability and the transformation of P_i to P_o . The amount of P_o in the mineral soil is generally higher at the surface, decreasing with depths. There are strong deviations from this trend, for example in the coarse textured sites (Figure 4-12) PSP 166, PSP 197 and SV 2 have as much or greater amounts of P_o at 1m depth as they do at the mineral surface. The fine textured natural profiles follow the pattern more closely, except for PSP 196 (Figure 4-13) which has extremely high $P_o:P_i$ ratios and relatively high and uniform amounts of total P throughout the profile. The LFH contributes little in most cases to the total amount of P_o to 1m depth.

There exists much variability in P_a in the coarse natural sites (Figure 4-12) compared to the relative uniformity in the fine natural sites (Figure 4-13). Some of the coarse natural sites have low P_a amounts, similar to the trend in the fine natural sites. Most, however, have higher amounts of P_a in the profile than the fine natural and reclaimed soils. The bulk of the P_a is held below the Ae horizons in the Bm horizons of these Eutric Brunisols (recall that PSP 163 just qualifies as a Dystric Brunisol with a pH in the B of 5.4).

4.5.4.2 Reclaimed soils

Mean values were plotted for the materials in the reclaimed profiles (Figure 4-14) because the data could be averaged by material, variability within materials was low (standard error bars are not plotted but were very small).

On average, the fine reclaimed profiles have relatively uniform distributions of P with depth and as reported earlier, have amounts of P_i , P_o and P_a similar to that of their natural fine textured counterparts.

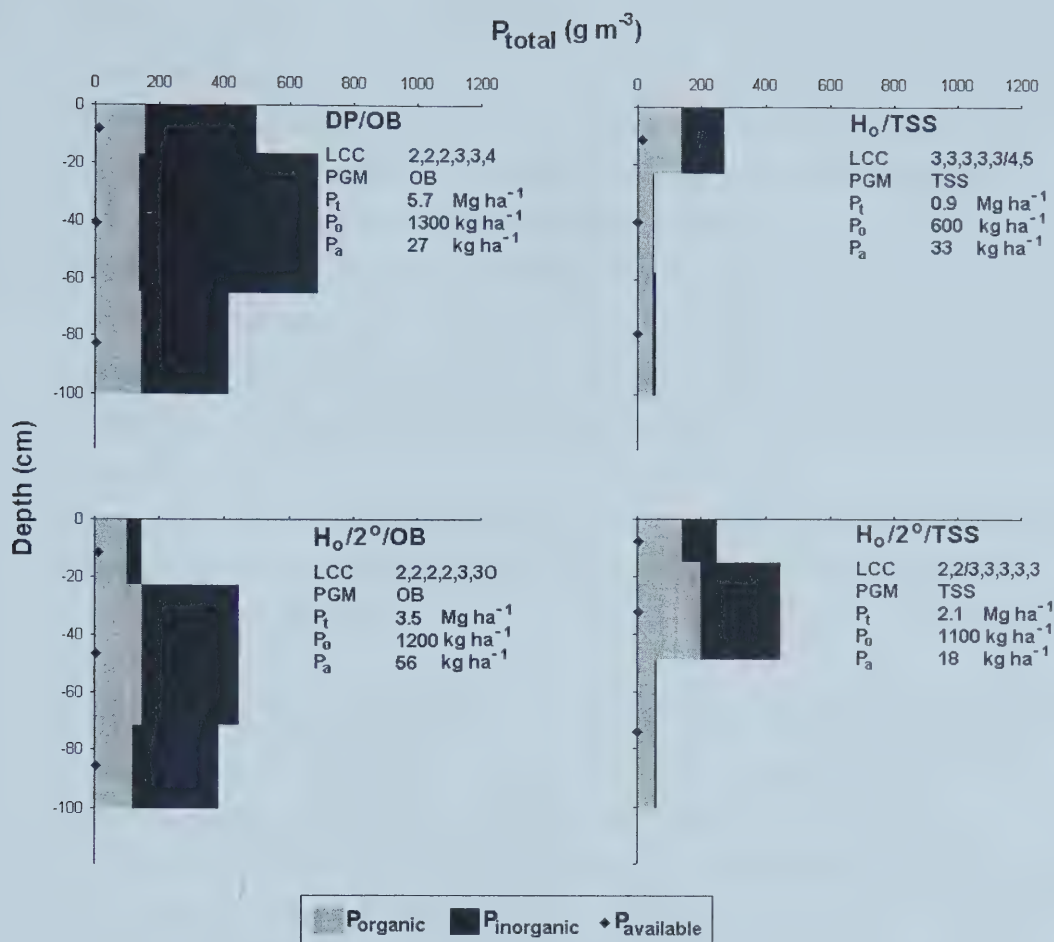


Figure 4-14. Stacked bar graphs for mean P profiles for reclaimed sites.

PGM: OB = overburden; TSS = tailings sand

The coarse textured profiles have a strikingly lower amount of P_t and P_i in the TSS material.

Neither the $H_o/2^\circ/TSS$ nor the H_o/TSS prescriptions have P_a bulges comparable to the fine coarse sites. For the $H_o/2^\circ/TSS$, the 'B' horizon or upper subsoil (US) is a fine textured layer and has a P_a amount comparable to the fine textured reclamation prescriptions.

4.6 Summary and conclusion

4.6.1 Forms and amounts of C, N and P in natural and reclaimed soils

The following is a brief summary of the important differences and observations with respect to total amounts and forms of C, N and P between the reclaimed soils and their natural analogues.

P_t No statistically significant difference in P_t to 1 m depth, but the H_o/TSS treatment relies heavily on the top 0.2 m of the profile for P_t and ten times as much P_t can be accounted

for by fertilization practices in this treatment compared to the other reclamation treatments (Figure 4-7).

- P_o** No statistically significant differences to 1 m depth or in the proportion in the top 0.2 m, however, the H_o/TSS has the lowest P_o content of all prescriptions with the greatest proportion being held in the top 0.2 m of the profile (Figure 4-9).
- P_a** Coarse textured natural soils have significantly more P_a to 1 m than the fine textured natural soils, 456 compared to 74 kg ha⁻¹. Of the 74 kg ha⁻¹, half is held in the top 0.2 m of the profile, while only a quarter of the 456 kg ha⁻¹ of the coarse soils is being held there. There exists a striking difference between these two natural treatments in terms of P_a (Figure 4-10: II).
- Both coarse textured reclamation prescriptions (H_o/TSS and H_o/2°/TSS) have significantly less P_a than the coarse natural analogues. The H_o/TSS prescription relies heavily on the peat amendment for its P_a with, on average, 80% being held in the top 0.2 m (Figure 4-10:I and II).
- N_t** The DP/OB prescription has significantly more N_t to 1 m than the fine natural analogues. Greater than ten times as much N_t can be accounted for by fertilization practices in the H_o/TSS treatment compared to the three reclamation treatments (Figure 4-8).
- N_a** Fine textured sites have significantly more N_a than coarse textured sites, regardless of soil type (natural or reclaimed) with 55 compared to 20 kg ha⁻¹ (Figure 4-10).
- C_t** There is significantly more C_t in the DP/OB and H_o/2°/TSS treatments compared to their respective natural analogues (fine and coarse) (Figure 4-11).
- C_o** No statistically significant difference in C_o to 1 m but that the fine textured reclamation prescriptions hold significantly more of the C_o to 1 m in the top 0.2 m of the profiles (Figure 4-11).

4.6.2 Distribution of P in natural and reclaimed soils

4.6.2.1 Natural soils

No characteristic shape can be used to describe the P profiles of either the fine or the coarse textured natural sites, although the fine soils are more uniformly distributed.

P_o does not necessarily decrease with depth in either the fine or coarse textured natural sites.

P_a is low and uniform with depth in the fine natural soils (on average 74 Mg ha⁻¹) while it is generally high in the Bm horizons of the coarse textured soils (accounting for an average amount of 456 Mg ha⁻¹).

P_a to 0.2 m depth is similar between textural groups, with 66 Mg ha⁻¹ for the fine and 37 Mg ha⁻¹ for the coarse textured soils.

4.6.2.2 Reclaimed soils

Fine textured reclaimed soils have similar amounts and distribution of P to 1 m depth.

Coarse textured reclaimed soils do not exhibit a bulge in P_a in the B horizon as do the coarse natural soils.

4.7 Discussion

4.7.1 P availability in natural soils

This striking difference in amounts of P_a between fine and coarse textured natural sites was not anticipated. However, using data reported by Macyk and Turchenek (1995) including P_t and P_a in $\mu\text{g g}^{-1}$, bulk density and horizon thickness, profiles similar to those in Figure 4-12 emerge with values for P_t of five sites ranges from 1.5 to 3.4 Mg ha⁻¹ and for P_a from 81 to 399 kg ha⁻¹ with an average of 250 kg ha⁻¹. Using similar data reported by Huang and Schoenau (1996) for a transect on a sandy loam glacial till in northern Saskatchewan, total amounts of P ranged from 4.6 to 6.4 Mg ha⁻¹ and P_a from 60 to 75 kg ha⁻¹ in the well drained members of the transect with profiles similar to Figure 4-13.

One possible mechanism accounting for the significantly higher P_a amounts in the coarse textured natural sites is the presence of secondary minerals, specifically Fe and Al oxide precipitates characteristic of the Bm horizons of sandy aeolian soils. The extent of Fe and Al oxide formation in the B, or the degree of podzolization, could then account for the variability in the P_a amounts observed in the coarse textured sites.

4.7.1.1 Proposed mechanism for high P_a in coarse textured natural soils: Podzolization

The production of organic acids at the soil surface as a result of organic matter decomposition accelerates the weathering of minerals at the soil surface. As the soil pH lowers, Fe and Al as well as some organic matter are solubilized and become mobile. These soluble constituents are translocated down the soil profile with the soil solution and precipitate at a depth where pH limits Al and Fe solubility. This process is known as podzolization and is characteristic of coarse textured soils (Buol et al. 1973; Brady and Weil 1996).

Both dissolved and amorphous Al and Fe precipitates can react with phosphate ions in solution. Phosphate ions can be precipitated with soluble Al and Fe forming relatively available (or extractable) Al and Fe phosphates. Anion exchange can be another important mechanism for phosphate reaction. As soil pH decreases, bonds in the alumina octahedral sheet of clays

(particularly 1:1-type) tend to form exposing OH⁻ groups which increase anion exchange capacity (Brady and Weil 1996). Although Spiers et al. (1989) reports significant amounts of 1:1 type clays in the Dover and Kinosis lacustrine materials of the region, the pH of Canadian soils is generally too high for strong development of anion exchange capacity. Its contribution to the availability of P in these soils is likely to be small.

A more likely mechanism contributing to the high amounts of P_a in these soils would be the displacement of OH⁻ ions from the Fe and Al oxides by phosphate ions in solution. These phosphates are less available to plants than are ions that are reversibly adsorbed through anion exchange but more readily available than the well aged crystalline minerals that form through stable binuclear bridges between Al or Fe oxides and phosphate. The Al and Fe oxides thereby act to reversible fix relatively available forms of P in the coarse textured soils.

4.7.1.2 Evidence of podzolization in coarse natural sites

4.7.1.2.1 Physical evidence: presence of secondary minerals

Fractionation of the 2000 - 53 µm and less than 53 µm fractions of the B and C horizons of the natural soils shows that P is concentrated in the fine soil fraction (less than 53 µm) (Figure 4-15). For P to be concentrated in the fine soil fraction requires that, at some point, P from primary minerals was transformed to secondary P-bearing minerals such as Al and Fe oxides since P is not a structural component of secondary minerals such as clays.

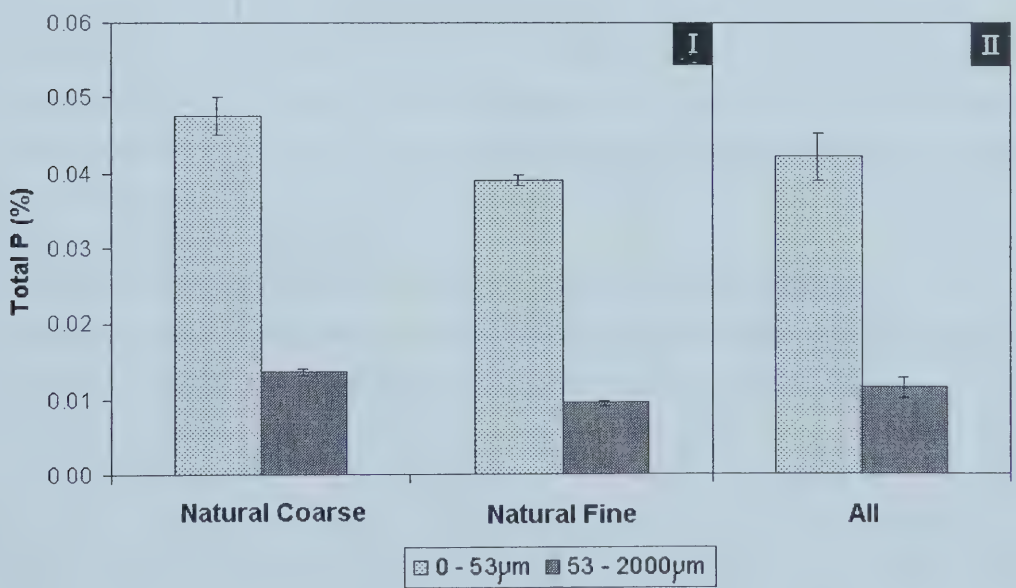


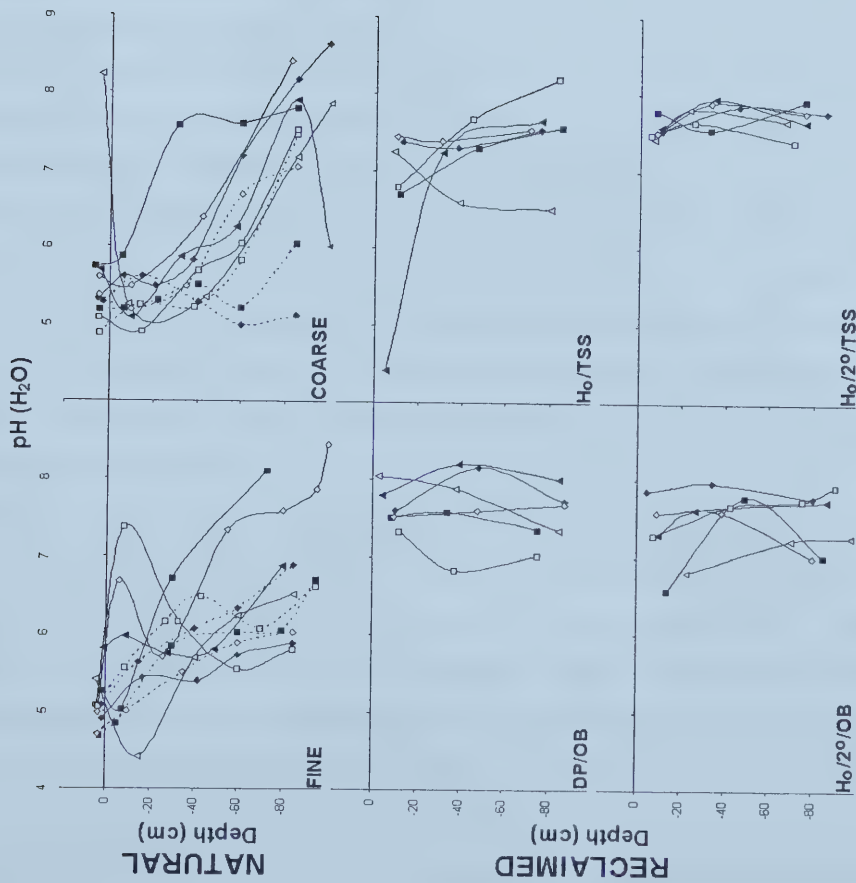
Figure 4-15. P as a function of two particles size fractions (2000 - 53 µm and < 53 µm) for the B and C horizons of natural sites.

4.7.1.2.2 Morphological evidence: Bm horizon development

A Bm soil pedogenic horizon can be characterized by higher chromas and redder hues than the underlying horizon, removal of carbonates and/or structural development (SVWG 1998). The B horizons of many soils developed on sandy parent materials in Alberta begin to resemble Podzolic Bf horizons which are characterized by significant enrichment with amorphous Al, Fe and organic materials of which hues redder than 7.5 YR and darker chromas are indicative. Some soils in Alberta of the Heart soil complex west and northwest of Edmonton (Dumanski 1970; Twardy and Lindsay 1971; Knapik and Lindsay 1983; Arocena 1991;) and near Fort Vermilion (Scheelar and Macyk 1972) have previously been classified as Podzolic based on the morphology in the field, but subsequent chemical analyses and revisions to the CSSC have revealed their lack of sufficient enrichment with extractable Al and Fe to qualify as Podzolic soils. The Heart complex is similar to the coarse textured soils considered in this study having similar depositional framework (aeolian modified glaciofluvial sands) and similar climate and vegetation. Alexander and Robertson (1968) report a bulge of Al- and Fe-bound P in the B horizon (then identified as a Bf) of a soil of the Heart series in northern Alberta corresponding with high amounts of P_i . P_a was not determined on the B horizons of that study, however, using samples of the same soil series, bulges in P_a of the Bm horizon were detected similar to the patterns observed in soils in Figure 4-12 (Unpublished data, Dr. J.A. Robertson, Professor Emeritus, Department of Renewable Resources, University of Alberta) with P_a values to 1 m of around 350 kg ha⁻¹. Macyk and Turchenek (1995) report that coarse natural soils in the AOSR are enriched in extractable Fe and Al in the Bm horizons which had increased chromes, compared to the parent material.

4.7.1.2.3 Chemical evidence: pH

According to Figure 4-16, the pH of the top 0.4 m of the profiles of the coarse natural sites is around 5.5 indicating that P fixation would be expected to be governed by Fe and Al phosphates. With depth, as the pH increases, P fixation would be expected to be governed more by Ca phosphates (Chapter 2).



Legend

NATURAL		RECLAIMED	
FINE	COARSE	H ₀ /20/OB	H ₀ /TSS
—■—	AUD2	93-2-2	SUN25
—○—	AUD3	94-2-21	SUN29
···■···	AUD4		
···○···	PSP164		
—◆—	PSP165	94-2-23	SUN38
—◇—	PSP173	94-2-26B	SUN61
···◆···	PSP196		
···◇···	PSP199		
—▲—	SV4	95-2-1	SUN77
—△—	SV6	96-2-19	SUN78
			97-2-8
			98-2-16
			99-2-13
			00-02-06

Figure 4-16. pH (H₂O) profiles for all sites in study according to treatment.

Although the pH profiles for the fine natural sites are similar to those of the coarse natural sites, increases in P_a are not found in the B horizon of the fine natural sites (zone below active elluviation). As pH decreases in fine textured soils, the destabilization and translocation of clays (léssivage) dominates rather than podzolization with the formation of Bt horizons, which are enriched with clays (Buol et al. 1973). The fine textured soils have more Ca in the form of $CaCO_3$ as indicated by the strong effervescence in the C horizons of half the soils, compared to only weak effervescence in two of the coarse soils[†] (Appendix D). This, in effect, buffers the weathering of Fe and Al minerals, preventing the solubilization of Fe and Al required for Al and Fe oxide formation in the B.

Based on the well recognized potential for aeolian sand materials in Alberta to undergo podzolization and the fact that high amounts of P_a in Figure 4-12 are associated with redder hues (7.5YR) than the underlying materials which are generally 10YR and/or increases in chroma by about 2 units, it is reasonable to conclude that translocation of Fe and likely Al has occurred in the coarse textured natural soils in Figure 4-12.

4.7.2 Implications for sand reclamation

The Clark process of oil bitumen extraction is a steam assisted NaOH extraction. Solutions containing OH^- ions hydrolyze Al and Fe, releasing P from Al and Fe phosphates (Chapter 2). The Olsen extraction for P_a determination (Olsen et al. 1954; Chapter 2) is a 0.5 M solution of $NaHCO_3$ with a pH near 8.5. The caustic soda of the Clark process has a pH of 8.5 to 11, being sufficiently high to extract all relatively available surface bound P from the quartz minerals. Macyk and Turchenek (1995) report fresh tailings having pH as high as 9.5. The P remaining in the TSS following extraction is in free Fe and Al oxides and primary P-bearing minerals. Significant weathering of the soil must take place for the development of Bm horizons which will retain P near the soil surface.

Decreases in pH for the top 5 cm of moraines in Alaska and the Yukon from pH 8 to around 6 or slightly less have been found to take 50 to 200 years (Crocker and Major 1955; Jacobson and Birks 1980) and can be expected to proceed more quickly in the poorly buffered TSS. The development of Bm horizons, however can be expected to take much longer. VandenBygaart and Protz (1994) found that the development of a 16 cm thick Bm horizon with a mere 0.2 point pH decrease from 7.4 to 7.2 and a two point increase in chroma with no hue change took 1000 years and 4700 years

[†] One coarse site has strong effervescence in the C horizons which are glaciolacustrine materials (see Appendix D).

for the development of a 39 cm thick horizon with a pH of 4.7 and chroma increase of an additional two points. Average precipitation in their study area was around 856 mm year⁻¹ with a mean annual temperature of 8.0°C compared to 389 mm year⁻¹ and 1.5°C in this study area. Soil development would be much slower in this climate making these figures optimistic.

Data for mineralogy of natural sands in the AOSR from Spiers et al. (1982) and the TSS from Mellon (1956), Creighton (1972) and Hein et al. (2000) suggest that the materials have similar amounts of Al and Fe bearing minerals however, Macyk and Turchenek (1995) report average values for total Fe in natural sand soils of around 0.5% (or 5000 µg g⁻¹) with the TSS around half, just below 0.25% (or 2500 µg g⁻¹). The natural sites in Figure 4-12 have on average 280 g m⁻³ of P in the mineral soil while the TSS of reclaimed soils of prescription 5 at Suncor have on average 49 g m⁻³ P and soils of prescription 6 at Syncrude have on average 61 g m⁻³ P. The natural sand soils have significantly more P_t, about five times as much, in the mineral soil as does the TSS. It would be expected, with one fifth the amount of P_t and half the amount of Fe, that the development of secondary Fe and P minerals be slower and/or expressed to a lesser degree in the TSS as compared to the natural sands in the region.

With inherently less P and Fe, TSS materials are not analogous to their coarse textured natural counterparts in the region. TSS reclamation prescriptions will fall short of predictions of soil and ecosystem development based on the natural analogues in the region.

4.8 Conclusion

Based on the statistical comparison and the forms and amounts of C, N and P and the qualitative evaluation of the distribution of P in natural and reclaimed soils in the AOSR, the following conclusions can be made:

1. Fine textured reclamation prescriptions examined have similar amounts of the forms of C, N and P as do their fine natural counterparts,
2. Fine textured reclamation prescriptions have more uniform distribution of P than do the natural soils, indicating that the natural soil have undergone translocation of P,
3. Coarse textured natural sites have less P_t to 1m, but significantly more P_a than do their fine textured counterparts,
4. The TSS soils have lower amounts of P_t (not significantly lower), but significantly less P_a to 1 m than the coarse natural analogues,
5. The H₀/TSS reclamation prescription, in particular, relies heavily on the surface horizon for C, N and P and heavily on fertilization for N and P capital.

It is proposed that the greater amount of P_a in the coarse natural sites is related to the ability of secondary minerals through podzolization in the Bm horizon to retain easily extractable forms of phosphorus. The development of Bm horizons in TSS materials is expected to be less extensive or complete than in the natural sites because the TSS material has about one fifth the amount of P_i and half the amount of Fe compared to natural sites making the TSS an inappropriate surrogate for the natural sands in the region.

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CHAPTER 5: SYNTHESIS

5.1 Summary

5.1.1 Natural soils

5.1.2 P content and accumulation of C and N

Weak relationships between P_t to 1 m and P_t concentration in the C horizon (PGM) and the C_o , N and P_o in the LFH and OM in the shallow mineral soil fail to support the hypothesis that the accumulation of OM is constrained to P. The current $C_o:P_o$, $N:P_o$ and $P_o:P_t$ ratios of the LFH and shallow mineral soils indicate that the systems are not stressed for P. This is not to suggest that P did not control C and N accumulation in early soil development. P likely controlled C and N accumulation in early soil development when P_a was in limited supply due to the slow release from primary minerals. P is currently available in sufficient amounts largely due to the decrease in pH. The current ratios of elements in SOM are more reflective of the dynamic biochemical cycles rather than the less dynamic pedogenic pathway.

5.1.3 P availability

The ratio of $P_a:P_t$ is different between fine and coarse textured soils in the region with 0.05 or less in fine material and approximately 0.13 in the coarse (Chapter 3). The fine textured natural sites have more P_t to 1 m (4.0 Mg ha^{-1}) compared to the coarse textured natural sites (2.8 Mg ha^{-1}) but the coarse textured sites have significantly greater amounts of P_a (456 versus 74 kg ha^{-1}) and very different P_a distributions with depth (Chapter 4). The proposed mechanism to account for the difference in amount and distribution of P_a is the presense of secondary Fe and Al minerals in the Bm horizons of the coarse textured soils. Acidification of the soil in fine textured soils results in the l ssivage, the destabilization and downward translocation of clays while in coarse textured soils it results in podzolization, the solubilization and translocation of OM, Fe and Al. Fe and Al retain relatively available forms of P near the surface, potentially accounting for the bulges of P_a in the B horizons of these soils.

The pH ranges between textural groups is similar: the coarse textured soils maintain a lower pH in the top 0.4 m of the soil profile than do the fine textured soils. Although the determination of P_a in soil samples with conventional extraction methods is dependent on soil pH an evaluation of the Bray, Olsen and modified Kelowna extractants showed that for the pH range of these soils, any of the three methods could be used for the determination of P_a (Chapter 2). More simply, the same conclusion regarding P_a in the natural soils would have been drawn regardless of which extractant method was selected. One can be confident that the difference in P_a between the

natural and reclaimed soils is a real difference, and not a function of the chemistry of the analytical procedure selected.

5.2 Reclaimed soils

Mature natural soils in the region are not suitable analogues for comparison to reclaimed soils. From a soil development or genesis perspective, reclaimed soils are more analogous to primary succession scenarios than secondary and virtually all soil processes require reestablishment. There are some indications of differences in elemental composition (specifically P_i and Fe) between the natural sands and the tailings sand, but the temporal disparity is paramount. Given sufficient time, reclaimed soils in the region will develop the necessary biogeochemical cycles. A more appropriate comparison would be the reclaimed ecosystems to the state of ecosystems in the region at time 0, prior to ecosystem development.

The question, then, is not “Can these reclaimed soils grow the trees I want *now*?” but rather “Will these reclaimed soils be able to support the desired ecosystems?” For the fine textured reclamation prescriptions that are using Wisconsinan glacial materials as well as a peat amendment, this study shows that from the P standpoint, these soils are similar to the fine textured natural soils in the region at time 0. The coarse textured reclamation prescriptions using TSS as a dominant proportion of the soil profile are not analogous to the natural glaciofluvial sands of the region at time 0.

5.2.1 Fine textured reclamation prescriptions

For fine textured reclamation to 1 m depth, there is no indication in this study that there should be any differences in amounts of P_i and P_a compared to natural analogues (Chapter 4). P_i profiles with depth are more uniform than the natural analogues, but total amounts of P to 1 m are similar. The amounts and distribution of P_a are low, but similar between the natural and reclaimed fine textured soils. Soil development will proceed with a reasonable degree of predictability.

5.2.2 Coarse textured reclamation prescriptions

For reclaimed soils with TSS comprising half or more of the soil profile to 1 m, data in this study indicate that these soils not only have less P_i to 1m but significantly lower capacity for supplying P_a. The two TSS prescriptions evaluated in this study, prescription 5 (H_o/TSS) and prescription 6 (H_o/2°/TSS), are amended with peat (H_o) with or without secondary till material (2°). Prescription 5 has one third the amount of P_i to 1 m than do natural sand soils while prescription 6 has only slightly less due to its till amendment which contributes significantly to its P_i.

The TSS alone compared to natural sand has about one fifth the amount of P and one half the amount of Fe. The development of Bm horizons in these materials is expected to be less extensive or complete than in the natural soils requiring a few thousand years. It is unknown, however, whether the P retained in these horizons contributes significantly to the P nutrition of plants and the overall sustainability of the ecosystem.

5.3 Recommendation

5.3.1 Appropriate comparisons

Comparison of reclaimed soils to mature natural analogues in the region from both a scientific perspective and a regulatory perspective is not appropriate. To expect these reclaimed systems to perform like mature natural systems 5 or 15 years after reclamation is analogous to expecting a newborn baby to walk. Unless the baby is physically crippled in some way, we can agree that she *will* walk when she's old enough. To determine if she is on target, we would compare her performance to that of her parents when they were babies, not to how her parents are performing now. The same goes for reclaimed soils: if they perform similar to other juvenile ecosystems or to target systems in the juvenile states, we can be confident that they will follow similar patterns.

5.3.2 Operational considerations

If the relatively available P retained in the Bm horizons of the natural coarse textured soils contributes to ecosystem productivity, then neither the TSS nor natural sands salvaged from depths below 0.5 m will initially have the mechanism in place to do so. In the mines where fine textured reclamation materials are unavailable, the selective salvage and placement of the LFH and the Bm horizons of the pre-disturbance landscapes has significant merit as a reclamation strategy. The discrete preservation and placement of both the LFH layers and the Bm horizon as a cap to TSS or at least the salvage of both in on lift will significantly reduce the time required for the reclaimed ecosystems to reach steady state and will reduce the amount of TSS in the soil profile.

Fertilization of the coarse textured soils must be exercised with care at a rate that is comparable to the rate of uptake by vegetation. If the soil is incapable of retaining P in early stages of development due to the lack of the necessary mechanism (herein proposed to be the presence of Al and Fe oxides in the B horizon) it is critical that the P added be retained through the fixation into organic matter.

5.4 Future research

5.4.1 Biogeochemical cycling

The first step in comparing the natural and reclaimed soils for any given element is the determination of the total capital. The next step is the **quantification of the rates** at which desired (and possibly undesired) transformations, translocations, additions and removals from the system are taking place.

The key to the sustainability of the reclaimed soils is the **reestablishment of biogeochemical cycles**. The peat amendments are useful physical media, but cannot be expected to cycle nutrients in a manner analogous to forest LFH horizons. The establishment of vegetation to capture and fix nutrients at the surface as they become available is essential to promote the formation of litter layers. The rates at which litter is being produced and the rates at which the nutrients are being mineralized are critical.

5.4.2 Soil development

Monitor soil development in reclaimed soils using **chronosequences** to determine the rates at which soil development is proceeding and comparing to chronosequences with similar parent materials and climate.

5.5 Concluding statement

The reclaimed materials, particularly the TSS, do not have the benefit of 10 000 years of soil development to their credit and as such are dissimilar to natural soils found in the region. Given sufficient time, all materials, including the TSS, will achieve a steady state that is a product of all interacting factors. If the time required to reach steady state is to be reduced significantly in sand reclamation, preservation of the pre-disturbance soil is critical.

APPENDIX A. PROJECTS AND MONITORING PROGRAMS FOR WHICH PLOTS ARE LINKED

Project	Owner	Objective	Natural	Reclaimed
Permanent Sample Plots (PSPs)	Alberta Pacific	Monitor long-term stand productivity	✓	
Soil and Vegetation (SV) monitoring plots	OSSVWG [†]	Monitor long-term soil quality, forest capability and ecosystem development of natural and reclaimed soils in the region	✓	✓
Capability plots	L.A. Leskiw [‡]	Calibrate LCC rating to stand productivity of young and old natural and reclaimed stands	✓	✓
Structure project	M.S. Yarmuch [§]	Evaluate the development of soil structure in reclaimed soils	✓	✓
Mineralization project	Y. Feng [¥]	Quantify mineralization rates of natural and reclaimed soils in the region	✓	✓
Phosphorus project (AUD)	A.V. Lanoue [£]	Examine the relation between P content of soil parent material to C and N accumulation in Boreal forest soils	✓	✓
Syncrude vegetation plots	Syncrude Canada Ltd.	Soil and vegetation monitoring		✓
Suncor monitoring transects	Suncor Energy	Soil and vegetation monitoring		✓

[†] Oil Sands Soil and Vegetation Working Group (Syncrude Canada Ltd., Suncor Energy and Albion Sands)

[‡] President, Paragon Soils and Environmental Services, Edmonton, Alberta

[§] M.Sc. Thesis, Department of Renewable Resources, University of Alberta

[¥] Professor, Department of Renewable Resources, University of Alberta

[£] Current project, M.Sc. Thesis, Department of Renewable Resources, University of Alberta

APPENDIX B. PREPARATION OF ION EXCHANGE RESIN (IER) BAGS FOR IN-SITU DETERMINATION OF AVAILABLE P AND N

Introduction

For basic information regarding ion exchange resins, their physical and chemical properties and some environmental applications of resins, see Skogley and Dobermann (1996). For the purposes of this study, IER bags were prepared according to Sibbesen (1977) and Binkley and Matson (1983). IER bags were extracted in a manner similar to that described by Binkley and Matson (1983). Slight modifications of the methods were made and are noted in the detailed method below.

Mixed bed ion exchange resin

Mixed bed ion exchange resin beads (IONAC ® NM-60, H⁺/OH⁻ Form, Type I, beads [16-50 Mesh]) were used. ‘Mixed’ refers to the presence of both anionic and cationic resin beads. Resin consists of a 1:1 chemically equivalent mixture of a Type I strong base anion resin and a strong acid cation resin. Particles size (mesh size) is closely controlled. IONAC NM-60 resin is used in producing high purity water for manufacturing and process industries, electronics industry, pharmaceutical industry, nuclear and power industries and for laboratory systems (Sybron Chemicals 2001).

Supplier

Moquin Scientifique
108 De Normandie Porte 2
Repentigny, Quebec
Canada J6A 6B9
Product Code: 4631-01
Lot Number: V14599

General purchasing specifications

Physical form:	spherical beads	
Ionic form shipped:	H ⁺ /OH ⁻	
Moisture content as Shipped (%):	59	
Volume ratio (approximate):	1.5 parts strong base anion 1.0 parts strong acid cation	
Polymer structure:	Cation: R-SO ₃ -H ⁺	(Hydrogen form sulphonated styrene divinylbenzene copolymer)
	Anion: R-(CH ₃) ₃ -N ⁺ OH ⁻	(Hydroxyl form alkyl quaternary ammonium styrene divinylbenzene copolymer)
Percent conversion to ionic form:	Hydrogen	95% minimum
	Hydroxide	90% minimum
	Chloride	4% maximum
	Sulfate & carbonate	6% maximum

IER bag preparation

Materials

- Plastic weigh boats
- Spoon
- Balance
- 100% Nylon stockings
- Plastic bags
- Latex gloves
- Mixed Bed Ion Exchange Resin IONAC® NM-60, H⁺/OH⁻ Form, Type I, beads (16-50 Mesh)
- 2M KCl (149.1 g KCl/L)

Methods

Latex gloves were worn at all times when handling all materials for the preparation of IER bags. Nylon (100%) stockings (pantyhose) were purchased and the legs were cut off from the point where the hose thickens on the thigh to ensure uniformity of the nylon mesh. Stockings were then submerged in 4 L of 2 M KCl in a plastic tub for 24 hours to prevent contamination of the resin by the stocking. Stockings were rinsed repeatedly with distilled water followed by deionized water and laid flat to dry on clean, dry paper towels for 24 hours.

Stockings were cut into 4 (~4 inches, 10 cm) sections (Figure B-1: A). One end was tied off as in B. 17 g of moist resin was weighed in clean, dry plastic weight boats and transferred to the stocking as in C. The end of the stocking was then tied off as in D. Resin bags were stored in new, air-tight plastic bags in groups of four (one bag per site) and stored at room temperature.

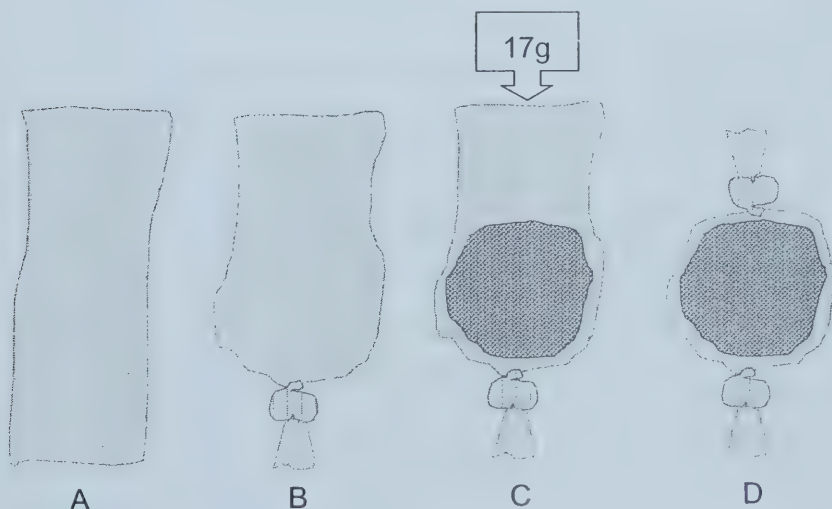


Figure B-1. Resin bags.

The mean weight of the resin bags was 17.019g ($n = 212$) with a standard deviation of 0.02. Bag weights ranged from a minimum weight of 16.95g to a maximum of 17.06g, a range of 0.11g.

Blanks

Thiffault et al. (2000) found ammonium and sulphur concentrations of their blanks in excess of the amounts that were expected in the field incubation. For their purposes, Thiffault et al. (2000)

proposed a pre-treatment of the resin prior to incubation to eliminate contaminants from the resin. When testing soils with very low amounts of available nutrients or for short incubations, pre-washing may be necessary. This procedure is also often used for recharging resin bags after use although Skogley and Doberman (1996) warn that Cl^- is not an effective sink for P ions and Sybron Chemicals (2001) recommend that IONAC NM-60 beads be used in non-regenerable applications (for use in water quality applications).

In his work Dan Binkley (Professor, Colorado State University) has found that subtracting the blanks is a suitable method of dealing with the adsorbed contaminants in each resin lot. Extraction of a set of bag ($n = 5$) and resin ($n = 5$) blanks was performed according to the extraction procedure outlined below prior to the incubation and subsequent extraction of the sample resin bags. Bag blanks were selected randomly from the lot ($n = 212$). Resin blanks consisted of 5-17g samples of resin sampled from one of the bottles in the lot.

IER Bag Extraction

Materials

- No. 42, ashless, 90mm, Whatman filter paper (catalogue No. 1442090)
- Mixed Bed Ion Exchange Resin IONAC® NM-60, H⁺/OH⁻ Form, Type I, beads (16-50 Mesh)
- bed shaker, model 60 CY. AC. 115 volts made by Eberach Corporation, Ann Arbor, Michigan 2N KCl (149.1 g KCl/L)
- solution dispenser
- funnels
- funnel rack
- 125mL nalgene bottles
- balance
- weigh boats
- paper towel
- latex gloves
- sample vials or bottles

Method

1. prepare enough 2N KCl (149.1 g KCl/L) solution for 100 ml per sample and rinsing of equipment
2. rinse all agene bottles, beakers, funnels, and any other glass-wear to be used with distilled water and 2M ACL before using
3. place all rinsed equipment on paper towel and wear gloves to avoid contamination
4. allow funnels to air dry on a funnel rack before using
5. cut one end of the resin bag open and transfer resin to 125 ml agene bottle and discard stocking bags
6. add 100 ml of 2N ACL using a solution dispenser
7. seal the agene bottles with caps and label
8. place all agene bottles on the bed shaker and agitate on high for 90 minutes
9. filter sample using Whatman No. 42 filter paper directly into sample vials/bottles
10. 20 ml of filtered extractant is required for analysis
11. seal vials/bottles
12. store in cool place until analyzed
13. analyze colorimetrically by the ascorbic molybdenum blue complex (Murphy and Riley 1962; Technicon 1973c) for $\text{PO}_4\text{-P}$ in extracts and ammonia-salicylate complex (Technicon 1973a; Technicon 1973b) $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ in extracts.

References

Binkley, D. and Matson, P. 1983. Ion exchange resin bag method for assessing forest soil nitrogen availability. *Soil Sci. Soc. Am. J.* 47: 1050-1052.

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- Skogley, E.O. and Dobermann, A. 1996.** Synthetic Ion-Exchange Resins: Soil and Environmental Studies. *J. Environ. Qual.* **25:** 13-24.
- Sybron Chemicals Inc. 2001.** IONAC® mixed bed ion exchange resins Information sheets. P.O. Box 66, Birmingham Road, Birmingham, New Jersey, USA, 08011. 1-800-678-0020.
- Technicon Autoanalyzer II. 1973a.** Ammonia in water and waste water. Industrial Method No. 90-70-W. Technicon Industrial Systems., Tarrytown, New York.
- Technicon Autoanalyzer II. 1973b.** Nitrate and nitrite in water and wastewater. Industrial Method No. 100-70W-B. Technicon Industrial Systems., Tarrytown, New York.
- Technicon Autoanalyzer II. 1973c.** Orthophosphate in water and seawater. Industrial Method No. 155-71-W. Technicon Industrial Systems., Tarrytown, New York.

APPENDIX C. SOIL CHEMICAL DATA

Lab ID	Site	Type [†]	Presc. [‡]	MIN/ORC ^α	Group ^β	Depth interval (cm) ^ζ	Horizon thickness (m) ^δ	Gravimetric w	Bulk density (Mg m ⁻³)	TEC (cmol(+) 100g ⁻¹) ^ε	CEC (cmol(+) 100g ⁻¹) ^φ	Soluble cations (meq L ⁻¹)			SAR ^γ
												Ca	Mg	Na	
194	SV 4	NAT	1	LFH COMP	CHEM					44.61	83.33				
165	SV 4	NAT	1	LFH	Db	9-0	0.09	0.86	0.14						
9	SV 4	NAT	1	MINERAL	CHEM	0-20	0.20	0.13	1.19						
12	SV 4	NAT	1	MINERAL	CHEM	20-45	0.25	0.17	1.59						
11	SV 4	NAT	1	MINERAL	CHEM	45-70	0.25	0.17	1.65						
10	SV 4	NAT	1	MINERAL	CHEM	70-85	0.30	0.17	1.65						
177	SV 6	NAT	1	LFH COMP	CHEM					33.20	80.37				
160	SV 6	NAT	1	LFH	Db	0-09	0.09	0.35	0.15						
14	SV 6	NAT	1	MINERAL	CHEM	0-17	0.17	0.11	1.65						
13	SV 6	NAT	1	MINERAL	CHEM	17-70	0.53	0.14	1.60						
15	SV 6	NAT	1	MINERAL	CHEM	70-100	0.30	0.14	1.60						
182	PSP 141	NAT	1	LFH COMP	CHEM					15.30	29.16				
169	PSP 141	NAT	1	LFH	Db	13-0	0.13	0.89	0.17						
55	PSP 141	NAT	1	MINERAL	CHEM	0-12	0.21 ψ	0.13	1.63						
53	PSP 141	NAT	1	MINERAL	CHEM	30-50	0.29 ψ	0.17	1.58						
52	PSP 141	NAT	1	MINERAL	CHEM	50-70	0.20	0.22	1.56						
54	PSP 141	NAT	1	MINERAL	CHEM	70-100	0.30	0.22	1.56						

[†] Type refers to Natural or Reclaimed

[‡] Presc. Refers to the prescription: 1 = fine textured natural soil; 2 = coarse textured natural soil; 3 = DP/OB; 4 = H₀/2^o/OB; 5 = H₀/TSS; 6 = H₀/2^o/TSS where DP = direct placement; OB = overburden; 2^o = secondary mineral material; TSS = tailings sand.

^α MIN/ORC refers to mineral or organic type: LFH COMP = LFH composite sample; LFH = LFH only; MINERAL = mineral soil only; TS COMP = topsoil composite sample

^β Group refers to analysis type: CHEM = chemical analysis only; Db = bulk density sample

^ζ refer to the actual depths from which soil was collected and do not necessarily agree with the morphological horizon thicknesses from Appendix D due to difficulties in sampling (e.g. coarse fragments, lost/missing samples). Explanations are provided below the data where they are required.

^δ Are the actual thicknesses used to determine total amounts of nutrients to 1 m depth. Are adjusted according to notes in χ in order to make up one full meter.

^ε TEC = total exchangeable cations (Ca, Mg, K, Na)

^φ CEC = cation exchange capacity

^γ SAR = sodium adsorption ratio

Lab ID	Site	Type ^a	Presc.	MIN/ORG ^a	Group ^b	Depth interval (cm) ^c	Horizon thickness (m) ^d	Gravimetric w	Bulk density (Mg m ⁻³)	TEC (cmol(+) 100g ⁻¹) ^e	CEC (cmol(+) 100g ⁻¹) ^f	Soluble cations (meq L ⁻¹)			SAR ^g
												Ca	Mg	Na	
ψ 12-30 cm sample missing, therefore 9 cm was added to the 0-12 cm and 30-50 cm samples as an approximation.															
PSP 141															
186	PSP 145	NAT	1	LFH COMP	CHEM										
162	PSP 145	NAT	1	LFH	Db	10-0	0.10	0.70	0.10	7.25	15.74				
68	PSP 145	NAT	1	MINERAL	CHEM	0-30	0.30	0.17	1.25						
66	PSP 145	NAT	1	MINERAL	CHEM	30-50	0.20	0.20	1.70						
67	PSP 145	NAT	1	MINERAL	CHEM	50-70	0.20	0.25	1.53						
69	PSP 145	NAT	1	MINERAL	CHEM	70-100	0.30	0.22	1.64						
189	PSP 149	NAT	1	LFH COMP	CHEM										
167	PSP 149	NAT	1	LFH	Db	9-0	0.09	1.13	0.18	9.59	22.80				
19	PSP 149	NAT	1	MINERAL	CHEM	0-14	0.14	0.15	1.59						
17	PSP 149	NAT	1	MINERAL	CHEM	14-30 ψ	0.16	0.22	1.49						
18	PSP 149	NAT	1	MINERAL	CHEM	30-50	0.20	0.22	1.49						
20	PSP 149	NAT	1	MINERAL	CHEM	50-70	0.20	0.20	1.62						
16	PSP 149	NAT	1	MINERAL	CHEM	70-90 £	0.30	0.15	1.74						
ψ Applied bulk density and moisture content from 30-50 cm sample. £ No sample for 90-100 cm; 70-100 cm is approximated by using the 70-90 cm chemistry.															
PSP 149															
199	PSP 164	NAT	1	LFH COMP	CHEM										
179	PSP 164	NAT	1	LFH	Db	9-0	0.09	0.99	0.06	15.52	41.67				
3	PSP 164	NAT	1	MINERAL	CHEM	15-28 ψ	0.28	0.14	1.71						
1	PSP 164	NAT	1	MINERAL	CHEM	28-50	0.22	0.15	1.74						0.39
2	PSP 164	NAT	1	MINERAL	CHEM	50-70	0.20	0.18	1.70						0.33
4	PSP 164	NAT	1	MINERAL	CHEM	70-105 £	0.30	0.18	1.70						0.19
ψ 0-15 cm sample missing/lost, therefore 0-28 cm is approximated by 15-28 cm chemistry. £ Thickness only 0.30 m because exceeds 1 m assessment depth.															
PSP 164															
196	PSP 165	NAT	1	LFH COMP	CHEM										
171	PSP 165	NAT	1	LFH	Db	10-0	0.10	1.69	0.05	3.61	7.06				
39	PSP 165	NAT	1	MINERAL	CHEM	8-13	0.13	0.18	1.49						
38	PSP 165	NAT	1	MINERAL	CHEM	13-28	0.15	0.01	1.65						
37	PSP 165	NAT	1	MINERAL	CHEM	28-48	0.20	0.01	1.65						

Lab ID	Site	Type ^{e†}	Presq; [‡]	MIN/ORG ^α	Group ^β	Depth interval (cm) ^γ	Horizon thickness (m) ^δ	Gravimetric w	Bulk density (Mg m ⁻³)	TEC (cmol(+) 100g ⁻¹) ^ε	CEC (cmol(+) 100g ⁻¹) [¶]	Soluble cations (meq L ⁻¹)			SAR ^γ
												Ca	Mg	Na	
36	PSP 165	NAT	1	MINERAL	CHEM	48-72	0.24	0.20	1.62						
35	PSP 165	NAT	1	MINERAL	CHEM	72-98	0.26	0.09	1.62						
34	PSP 165	NAT	1	MINERAL	CHEM	112-140 ψ	0.02	0.09	1.62						
PSP 165	ψ Thickness only 0.02 m because exceeds 1 m assessment depth.														
181	PSP 173	NAT	1	LFH COMP	CHEM					27.06	45.43				
172	PSP 173	NAT	1	LFH	Db	10-0	0.10	1.09	0.09						
42	PSP 173	NAT	1	MINERAL	CHEM	0-20 ψ	0.30	0.17	1.39						
40	PSP 173	NAT	1	MINERAL	CHEM	30-64	0.34	0.22	1.46						
41	PSP 173	NAT	1	MINERAL	CHEM	64-100	0.36	0.06	1.77						
PSP 173	ψ No 20-30 cm sample, therefore, 0-20 cm sample was extended to 30 cm to approximate 0-30 cm.														
195	PSP 196	NAT	1	LFH COMP	CHEM					9.53	20.64				
161	PSP 196	NAT	1	LFH	Db	6-0	0.06	0.63	0.13						
73	PSP 196	NAT	1	MINERAL	CHEM	0-30	0.30	0.12	1.68						
70	PSP 196	NAT	1	MINERAL	CHEM	30-50	0.20	0.18	1.74						
71	PSP 196	NAT	1	MINERAL	CHEM	50-70	0.20	0.16	1.77						
72	PSP 196	NAT	1	MINERAL	CHEM	70-100	0.30	0.16	1.76						
187	PSP 199	NAT	1	LFH COMP	CHEM					6.44	14.36				
164	PSP 199	NAT	1	LFH	Db	10-0	0.10	0.86	0.11						
33	PSP 199	NAT	1	MINERAL	CHEM	0-20	0.20	0.13	1.41						
32	PSP 199	NAT	1	MINERAL	CHEM	20-50	0.30	0.15	1.71						
29	PSP 199	NAT	1	MINERAL	CHEM	50-70	0.20	0.14	1.81						
31	PSP 199	NAT	1	MINERAL	CHEM	70-100	0.30	0.18	1.75						
198	AUD 2	NAT	2	LFH COMP	CHEM					4.69	10.51				
175	AUD 2	NAT	2	LFH	Db	3-0	0.03	0.17	0.10						
30	AUD 2	NAT	2	MINERAL	CHEM	0-15	0.09 £	0.10	1.50						
28	AUD 2	NAT	2	MINERAL	CHEM	15-45	0.05 £	0.88	1.62						
26	AUD 2	NAT	2	MINERAL	CHEM	18-24	0.11 £	0.04	1.73						
27	AUD 2	NAT	2	MINERAL	CHEM	40-75	0.36 £	0.88	1.62						

Lab ID	Site	Type ^t	Presc ⁺	MIN/ORG ^z	Group ^β	Depth interval (cm) ^z	Horizon thickness (m) ^δ	Gravimetric w	Bulk density (Mg m ⁻³)	TEC (cmol(+) 100g ⁻¹) ^ε	CEC (cmol(+) 100g ⁻¹) ^φ	Soluble cations (meq L ⁻¹)			SAR ^γ
												Ca	Mg	Na	
ψ High volume of coarse fragments made it difficult to sample by horizon, Depth intervals have overlap. See £.															
£ Coarse fragment adjustment to mineral soil: 40% coarse fragments; 0.60 multiplier															
183	AUD 3	NAT	2	LFH COMP	CHEM	7.5-0	0.07	0.33	0.12	5.72	20.46				
173	AUD 3	NAT	2	LFH	Db	0-16	0.16	0.03	1.40						
79	AUD 3	NAT	2	MINERAL	CHEM	16-50	0.34	0.03	1.62						
81	AUD 3	NAT	2	MINERAL	CHEM	50-70	0.20	0.04	1.66						
78	AUD 3	NAT	2	MINERAL	CHEM	70-100	0.30	0.04	1.58						
80	AUD 3	NAT	2	MINERAL	CHEM										
185	AUD 4	NAT	2	LFH COMP	CHEM	5-0	0.05	0.23	0.12	4.31	20.46				
170	AUD 4	NAT	2	LFH	Db	0-10	0.10	0.05	1.44						
47	AUD 4	NAT	2	MINERAL	CHEM	20-50	0.40 ψ	0.06	1.58						
50	AUD 4	NAT	2	MINERAL	CHEM	50-70	0.20	0.04	1.63						
49	AUD 4	NAT	2	MINERAL	CHEM	70-90	0.20	0.04	1.63						
51	AUD 4	NAT	2	MINERAL	CHEM	90-115 £	0.10	0.04	1.67						
48	AUD 4	NAT	2	MINERAL	CHEM										
(Chemistry for 20-50 cm was applied to 10-50 cm for 0.40 m thickness. £ Thickness only 0.10 m because range goes past 1 m assessment depth.															
193	PSP 161	NAT	2	LFH COMP	CHEM	6-0	0.03	0.48	0.12	5.88	16.28				
168	PSP 161	NAT	2	LFH	Db	0-18	0.18	0.05	1.45						
85	PSP 161	NAT	2	MINERAL	CHEM	18-36	0.18	0.07	1.59						
84	PSP 161	NAT	2	MINERAL	CHEM	36-50	0.14	0.04	1.63						
83	PSP 161	NAT	2	MINERAL	CHEM	50-90	0.40	0.08	1.72						
82	PSP 161	NAT	2	MINERAL	CHEM	90-110 (	0.10	0.08	1.72						
21	PSP 161	NAT	2	MINERAL	CHEM										
(Thickness only 0.10 m because range goes past 1 m assessment depth. Applied bulk density and moisture content from 50-90 cm sample.															
197	PSP 163	NAT	2	LFH COMP	CHEM	3-0	0.03	0.29	0.17	1.85	6.46				
178	PSP 163	NAT	2	LFH	Db	15-33 ψ	0.33	0.06	1.59						
23	PSP 163	NAT	2	MINERAL	CHEM	33-50	0.17	0.06	1.56						
24	PSP 163	NAT	2	MINERAL	CHEM										

Lab ID	Site	Type [†]	Pres [‡]	MIN/ORG ^α	Group ^β	Depth interval (cm) ^γ	Horizon thickness (m) ^δ	Gravimetric w	Bulk density (Mg m ⁻³)	TEC (cmol(+) 100g ⁻¹) ^ε	CEC (cmol(+) 100g ⁻¹) ^θ	Soluble cations (meq L ⁻¹)			SAR ^γ
												Ca	Mg	Na	
22	PSP 163	NAT	2	MINERAL	CHEM	50-60	0.10	0.04	1.59						
25	PSP 163	NAT	2	MINERAL	CHEM	60-100	0.40	0.04	1.59						
190	PSP 163	ψ 0 - 33 cm sample missing/lost, therefore 0-33 cm is approximated using the 15-33 cm chemistry.													
190	PSP 166	NAT	2	LFH COMP	CHEM										
176	PSP 166	NAT	2	LFH	Db	6-0	0.06	0.89	0.07	9.05	26.47				
59	PSP 166	NAT	2	MINERAL	CHEM	0-12	0.12	0.08	1.56						
61	PSP 166	NAT	2	MINERAL	CHEM	12-40	0.28	0.07	1.73						
58	PSP 166	NAT	2	MINERAL	CHEM	40-70	0.30	0.08	1.85						
60	PSP 166	NAT	2	MINERAL	CHEM	70-90	0.20	0.08	1.78						
56	PSP 166	NAT	2	MINERAL	CHEM	90-110 ψ	0.10	0.08	1.78						
57	PSP 166	NAT	2	MINERAL	CHEM	110-130 £	0.00	0.08	1.78						
	PSP 166	ψ Thickness only 0.10 m because range goes past 1 m assessment depth. £ Thickness is 0.00 m because exceeds 1 m assessment depth.													
184	PSP 171	NAT	2	LFH COMP	CHEM										
180	PSP 171	NAT	2	LFH	Db	3-0	0.03	0.25	0.21	3.45	16.29				
43	PSP 171	NAT	2	MINERAL	CHEM	0-30	0.30	0.08	1.40						
44	PSP 171	NAT	2	MINERAL	CHEM	30-50	0.20	0.04	1.68						
45	PSP 171	NAT	2	MINERAL	CHEM	50-70	0.20	0.05	1.72						
46	PSP 171	NAT	2	MINERAL	CHEM	70-100	0.30	0.06	1.59						
191	PSP 197	NAT	2	LFH COMP	CHEM										
163	PSP 197	NAT	2	LFH	Db	7-0	0.07	0.63	0.09	2.55	8.05				
77	PSP 197	NAT	2	MINERAL	CHEM	0-20	0.20	0.07	1.44						
75	PSP 197	NAT	2	MINERAL	CHEM	20-50	0.30	0.11	1.45						
74	PSP 197	NAT	2	MINERAL	CHEM	50-70	0.20	0.04	1.76						
76	PSP 197	NAT	2	MINERAL	CHEM	70-100	0.30	0.06	1.76						
188	SV 10	NAT	2	LFH COMP	CHEM										
174	SV 10	NAT	2	LFH	Db	2-0	0.02	0.69	0.08	5.42	11.70				
5	SV 10	NAT	2	MINERAL	CHEM	0-18	0.18	0.03	1.28						

Lab ID	Site	Type [†]	P _{resc} [‡]	MIN/ORG ^α	Group ^β	Depth interval (cm) ^χ	Horizon thickness (m) [§]	Gravimetric w	Bulk density (Mg m ⁻³)	TEC (cmol(+) 100g ⁻¹) ^ε	CEC (cmol(+) 100g ⁻¹) ^φ	Soluble cations (meq L ⁻¹)			SAR ^γ
												Ca	Mg	Na	
6	SV 10	NAT	2	MINERAL	CHEM	18-38	0.20	0.03	1.57						
8	SV 10	NAT	2	MINERAL	CHEM	38-60	0.22	0.03	1.56						
7	SV 10	NAT	2	MINERAL	CHEM	60-100	0.40	0.03	1.55						
192	SV 2	NAT	2	LFH COMP	CHEM					11.78	28.97				
166	SV 2	NAT	2	LFH	Db	9-0	0.09	0.64	0.10						
65	SV 2	NAT	2	MINERAL	CHEM	10-30 ψ	0.30	0.05	1.33						
64	SV 2	NAT	2	MINERAL	CHEM	30-50	0.20	0.06	2.49						
62	SV 2	NAT	2	MINERAL	CHEM	50-70	0.20	0.12	1.48						
63	SV 2	NAT	2	MINERAL	CHEM	70-100	0.30	0.09	1.59						
	SV 2	ψ 0-10 sample lost/missing, therefore 0-30 cm is approximated using the 20-30 cm chemistry.													
155	90-1-5	REC	3	TS COMP	CHEM	0-18	0.18	0.18	1.00	19.01	18.66	8.20	3.50	0.33	0.13
96	90-1-5	REC	3	MINERAL	CHEM	18-50	0.29 ψ	0.11	1.30	43.14	28.94	11.00	3.83	3.17	1.17
97	90-1-5	REC	3	MINERAL	CHEM	50-100	0.45 ψ	0.20	1.12			23.50	8.25	8.04	2.02
	90-1-5	ψ Coarse fragment adjustment: 10% coarse fragments; 0.9 multiplier.													
145	90-2-1	REC	3	TS COMP	CHEM	0-25	0.25	0.18	0.99	36.59	33.99	11.52	6.32	0.87	0.29
112	90-2-1	REC	3	MINERAL	CHEM	25-50	0.25	0.16	1.12	32.69	21.66	24.52	24.99	5.83	1.17
113	90-2-1	REC	3	MINERAL	CHEM	50-100	0.50	0.23	1.27			33.52	17.90	7.48	1.47
140	90-2-2	REC	3	TS COMP	CHEM	0-21	0.21	0.30	1.24	35.85	39.10	3.55	2.33	0.96	0.56
130	90-2-2	REC	3	MINERAL	CHEM	21-75	0.54	0.13	1.87	35.94	7.77	11.00	4.67	3.83	1.37
131	90-2-2	REC	3	MINERAL	CHEM	75-100	0.25	0.09	1.77			13.00	4.75	1.26	0.42
142	90-2-3	REC	3	TS COMP	CHEM	0-20	0.20	0.12	1.11	21.46	12.13	4.65	2.00	0.40	0.22
110	90-2-3	REC	3	MINERAL	CHEM	20-75	0.55	0.10	1.20	28.60	26.05	4.77	2.24	0.85	0.45
111	90-2-3	REC	3	MINERAL	CHEM	75-100	0.25	0.16	0.97			5.12	2.32	1.04	0.54
154	92-1-7	REC	3	TS COMP	CHEM	0-9	0.09	0.09	1.51	21.90	14.43	6.50	3.08	0.35	0.16
120	92-1-7	REC	3	MINERAL	CHEM	9-70	0.61	0.07	1.83	37.53	7.03	1.62	0.83	1.43	1.30
121	92-1-7	REC	3	MINERAL	CHEM	70-100	0.30	0.11	1.64			1.82	0.77	1.35	1.18
147	92-1-8	REC	3	TS COMP	CHEM	0-6	0.06	0.16	1.35	27.80	19.26	4.25	2.17	0.57	0.32
122	92-1-8	REC	3	MINERAL	CHEM	6-70	0.64	0.20	1.43	29.62	16.05	12.50	7.00	4.30	1.38

Lab ID	Site	Type ^a	Presc. ‡	MIN/ORG ^α	Group ^β	Depth interval (cm) ^γ	Horizon thickness (m) ^δ	Gravimetric w	Bulk density (Mg m ⁻³)	TEC (cmol(+) 100g ⁻¹) ^ε	CEC (cmol(+) 100g ⁻¹) ^θ	Soluble cations (meq L ⁻¹)			SAR ^γ
												Ca	Mg	Na	
123	92-1-8	REC	3	MINERAL	CHEM	70-100	0.30	0.11	1.70			9.75	5.50	3.13	1.13
137	93-2-2	REC	4	TS COMP	CHEM	0-28	0.28	0.71	0.56	31.11	52.42	5.20	2.83	1.41	0.71
127	93-2-2	REC	4	MINERAL	CHEM	28-70	0.42	0.15	1.65	22.61	7.86	17.77	6.57	2.87	0.82
126	93-2-2	REC	4	MINERAL	CHEM	70-100	0.30	0.09	1.46			27.00	12.92	3.30	0.74
153	94-2-21	REC	4	TS COMP	CHEM	0-15	0.15	0.43	0.76	31.32	39.08	8.30	3.67	0.40	0.16
132	94-2-21	REC	4	MINERAL	CHEM	15-70	0.55	0.12	1.92			22.00	6.75	3.13	0.83
134	94-2-21	REC	4	MINERAL	CHEM	70-80	0.10	0.19	1.72			16.00	5.25	3.74	1.15
133	94-2-21	REC	4	MINERAL	CHEM	80-100	0.20	0.19	1.72			14.00	5.25	3.83	1.23
135	94-2-23	REC	4	TS COMP	CHEM	0-9	0.09	0.72	0.39	46.98	26.87	7.50	2.92	0.68	0.30
91	94-2-23	REC	4	MINERAL	CHEM	9-60	0.51	0.12	1.70	29.71	10.83	3.82	2.90	3.13	1.71
90	94-2-23	REC	4	MINERAL	CHEM	60-100	0.40	0.16	1.62			13.02	5.49	5.91	1.94
149	94-2-26A	REC	4	TS COMP	CHEM					33.80	33.14	5.90	2.67	0.36	0.17
138	94-2-26B	REC	4	TS COMP	CHEM	0-18	0.18	0.97	0.31	52.26	48.43	7.00	1.92	0.40	0.19
87	94-2-26B	REC	4	MINERAL	CHEM	18-60	0.42	0.18	1.77	15.41	8.30	18.52	7.57	1.83	0.51
86	94-2-26B	REC	4	MINERAL	CHEM	60-100	0.40	0.12	1.81			10.77	4.74	2.17	0.78
152	95-2-1	REC	4	TS COMP	CHEM	0-20	0.20	0.87	0.32	72.95	75.72	17.00	3.33	0.91	0.29
95	95-2-1	REC	4	MINERAL	CHEM	20-73	0.53	0.19	1.59	18.39	9.73	24.77	19.99	9.57	2.02
94	95-2-1	REC	4	MINERAL	CHEM	73-100	0.27	0.17	1.66			10.27	5.82	8.43	2.97
139	96-2-19	REC	4	TS COMP	CHEM	0-46	0.46	0.82	0.37	77.32	88.79	7.70	3.67	0.98	0.41
124	96-2-19	REC	4	MINERAL	CHEM	46-94	0.48	0.22	1.59	32.89	21.40	23.27	11.65	9.78	2.34
125	96-2-19	REC	4	MINERAL	CHEM	94-100	0.06	0.15	1.79			38.52	14.15	10.43	2.03
141	SUN 25	REC	5	TS COMP	CHEM	0-23	0.23	0.12	0.82	4.15	5.49	2.80	1.54	0.24	0.17
101	SUN 25	REC	5	MINERAL	CHEM	23-70	0.47	0.03	1.56	2.68	0.81	1.22	0.44	0.47	0.51
100	SUN 25	REC	5	MINERAL	CHEM	70-100	0.30	0.06	1.53			1.52	0.66	0.27	0.26
157	SUN 29	REC	5	TS COMP	CHEM	0-21	0.21	0.04	1.25	7.81	13.85	4.20	2.33	0.40	0.22
107	SUN 29	REC	5	MINERAL	CHEM	21-67	0.46	0.02	1.57	1.46	0.84	1.47	0.84	0.22	0.21
106	SUN 29	REC	5	MINERAL	CHEM	67-100	0.33	0.05	1.49			1.42	0.85	0.21	0.20
148	SUN 38	REC	5	TS COMP	CHEM	0-25	0.25	0.02	1.41	14.20	11.40	15.50	6.50	0.33	0.10

Lab ID	Site	Type ^t	Presc. ^t	MIN/ORG ^a	Group ^b	Depth interval (cm) ^z	Horizon thickness (m) ^δ	Gravimetric w	Bulk density (Mg m ⁻³)	TEC (cmol(+) 100g ⁻¹) ^ε	CEC (cmol(+) 100g ⁻¹) ^ε	Soluble cations (meq L ⁻¹)			SAR ^γ
												Ca	Mg	Na	
129	SUN 38	REC	5	MINERAL	CHEM	25-50	0.25	0.03	1.48	0.86	0.73	2.10	1.11	0.34	0.27
128	SUN 38	REC	5	MINERAL	CHEM	50-100	0.50	0.06	1.47			1.80	1.44	0.35	0.27
159	SUN 61	REC	5	TS COMP	CHEM	0-20 ψ	0.12	0.08	1.20	24.27	27.73	10.25	5.08	0.35	0.13
118	SUN 61	REC	5	MINERAL	CHEM	20-40 ψ	0.12	0.08	1.20	32.55	25.24	5.82	3.49	0.43	0.20
119	SUN 61	REC	5	MINERAL	CHEM	40-100	0.60	0.03	1.64			3.22	1.44	0.23	0.15
	SUN 61	ψ Coarse fragment adjustment: 40% coarse fragments; 0.6 multiplier.													
150	SUN 77	REC	5	TS COMP	CHEM	0-11	0.11	0.10	1.10	10.29	19.68	18.00	15.21	0.33	0.08
117	SUN 77	REC	5	MINERAL	CHEM	11-50	0.39	0.04	1.59	1.43	0.89	18.52	4.90	0.33	0.10
116	SUN 77	REC	5	MINERAL	CHEM	50-100	0.50	0.04	1.58			7.72	4.15	0.29	0.12
158	SUN 78	REC	5	TS COMP	CHEM	0-17	0.17	0.16	1.07	42.59	48.58	7.80	3.83	0.27	0.11
108	SUN 78	REC	5	MINERAL	CHEM	17-60	0.43	0.02	1.50	0.54	0.61	1.17	0.79	0.18	0.18
109	SUN 78	REC	5	MINERAL	CHEM	60-100	0.40	0.03	1.47			0.67	0.52	0.27	0.34
146	92-2-5	REC	6	TS COMP	CHEM	0-15	0.15	0.18	1.27	36.10	14.39	6.30	2.25	1.43	0.69
99	92-2-5	REC	6	MINERAL	CHEM	15-50	0.35	0.17	1.35	27.02	16.28	22.00	7.33	13.48	3.52
98	92-2-5	REC	6	MINERAL	CHEM	50-100	0.50	0.05	1.60			2.67	0.85	1.43	1.08
143	00-02-06	REC	6	TS COMP	CHEM	0-13	0.13	0.35	0.76	45.99	52.67	16.52	4.40	1.00	0.31
102	00-02-06	REC	6	MINERAL	CHEM	13-32	0.19	0.16	1.67	25.27	11.54	11.02	5.07	3.78	1.33
103	00-02-06	REC	6	MINERAL	CHEM	32-100	0.68	0.04	1.65			0.97	1.65	0.58	0.51
151	94-2-13	REC	6	TS COMP	CHEM	0-10	0.10	0.32	0.96	27.89	20.11	7.90	2.42	0.58	0.26
105	94-2-13	REC	6	MINERAL	CHEM	10-40	0.30	0.13	1.51	42.21	19.51	6.02	3.49	1.35	0.62
104	94-2-13	REC	6	MINERAL	CHEM	40-100	0.60	0.12	1.68			2.02	1.49	1.09	0.82
136	94-2-31	REC	6	TS COMP	CHEM	0-20	0.20	0.30	0.81	42.94	42.77	11.75	3.75	1.22	0.44
115	94-2-31	REC	6	MINERAL	CHEM	20-70	0.50	0.15	1.68	27.63	14.06	3.92	2.49	3.61	2.02
114	94-2-31	REC	6	MINERAL	CHEM	70-100	0.30	0.02	1.63			2.97	1.65	1.91	1.26
156	96-2-16	REC	6	TS COMP	CHEM	0-15	0.15	0.42	0.55	39.17	40.73	6.50	3.33	1.17	0.53
92	96-2-16	REC	6	MINERAL	CHEM	15-50	0.35	0.17	1.63	25.57	8.36	4.82	2.99	4.09	2.07
93	96-2-16	REC	6	MINERAL	CHEM	50-100	0.50	0.03	1.50			2.02	1.36	2.43	1.87
144	97-2-8	REC	6	TS COMP	CHEM	0-19	0.19	0.40	0.59	56.75	52.44	10.27	2.82	1.17	0.46

Lab ID	Site	Type [†]	Presc. [‡]	MIN/ORG ^α	Group ^β	Depth interval (cm) ^γ	Horizon thickness (m) ^δ	Gravimetric w	Bulk density (Mg m ⁻³)	TEC (cmol(+) 100g ⁻¹) ^ε	CEC (cmol(+) 100g ⁻¹) ^φ	Soluble cations (meq L ⁻¹)			SAR ^γ
												Ca	Mg	Na	
88	97-2-8	REC	6	MINERAL	CHEM	19-50	0.31	0.09	1.89	22.34	6.80	12.52	5.49	8.70	2.90
89	97-2-8	REC	6	MINERAL	CHEM	50-100	0.50	0.02	1.46			1.87	1.24	1.35	1.08

Lab ID	Site	Type	Presc.	MIN/ORG	Group	pH		Saturated paste		N _{available} ⁿ			P _{total} ¹	P _{available} ^o PO ₄ -P (ppm)	P _{inorganic} ^κ (ppm)	N _{total} ^λ (%)	C _{total} ^μ (%)	C _{organic} ^ν (%)
						H ₂ O	CaCl ₂	pH	E.C. (mS cm ⁻¹)	NO ₃ -N (ppm)	NH ₄ -N (ppm)	(%)						
194	SV 4	NAT	1	LFH COMP	CHEM	5.7				7.57	37.85	0.078	46.90	118.15	0.952	23.13	22.99	
165	SV 4	NAT	1	LFH	Db	5.08				24.19	120.95	0.074	176.20	220.00	1.067	39.07	38.75	
9	SV 4	NAT	1	MINERAL	CHEM	5.86				0.73	3.65	0.017	4.79	40.50	0.077	1.16	1.22	
12	SV 4	NAT	1	MINERAL	CHEM	6.26				0.41	2.05	0.019	1.60	96.50	0.049	0.62	0.63	
11	SV 4	NAT	1	MINERAL	CHEM	7.91				0.20	1.00	0.031	1.79	266.64	0.041	1.00	0.66	
10	SV 4	NAT	1	MINERAL	CHEM	8.23	7.12		0.18	0.20	1.00	0.026	1.10	249.98	0.029	1.04	0.42	
177	SV 6	NAT	1	LFH COMP	CHEM	5.19				3.97	19.85	0.056	18.15	54.13	0.728	19.15	18.96	
160	SV 6	NAT	1	LFH	Db	5.25				10.53	52.65	0.052	65.84	100.38	0.676	23.39	23.17	
14	SV 6	NAT	1	MINERAL	CHEM	5.34				0.72	3.60	0.014	1.69	18.50	0.099	1.80	1.76	
13	SV 6	NAT	1	MINERAL	CHEM	7.17				0.22	1.10	0.019	1.40	84.79	0.041	0.57	0.58	
15	SV 6	NAT	1	MINERAL	CHEM	7.87	7.34		0.98	0.22	1.10	0.024	1.20	199.98	0.033	1.36	0.74	
182	PSP 141	NAT	1	LFH COMP	CHEM	5.73				3.56	17.80	0.042	17.40	61.07	0.261	5.12	5.14	
169	PSP 141	NAT	1	LFH	Db	6.29				60.94	304.70	0.125	220.59	396.00	1.497	35.30	35.05	
55	PSP 141	NAT	1	MINERAL	CHEM	5.88				0.53	2.65	0.024	1.10	52.90	0.063	0.75	0.74	
53	PSP 141	NAT	1	MINERAL	CHEM	7.57				0.24	1.20	0.026	1.80	144.62	0.042	0.68	0.68	
52	PSP 141	NAT	1	MINERAL	CHEM	7.6				0.31	1.55	0.041	2.91	288.86	0.042	0.64	0.53	
54	PSP 141	NAT	1	MINERAL	CHEM	7.81	7.47		1.14	0.36	1.80	0.043	2.60	327.75	0.041	1.05	0.50	
186	PSP 145	NAT	1	LFH COMP	CHEM	5.08				1.65	8.25	0.023	6.94	32.22	0.121	2.37	2.28	
162	PSP 145	NAT	1	LFH	Db	5.14				31.79	158.95	0.080	212.25	247.50	0.970	32.24	32.40	
68	PSP 145	NAT	1	MINERAL	CHEM	4.89				1.24	6.20	0.017	2.30	25.70	0.066	0.89	0.91	
66	PSP 145	NAT	1	MINERAL	CHEM	5.7				0.67	3.35	0.020	1.88	58.54	0.046	0.53	0.52	

ⁿ available nitrogen¹ total phosphorus^o available phosphorus^κ inorganic phosphorus^λ total/organic nitrogen^μ total carbon^ν organic carbon

Lab ID	Site	Type	Presc.	MIN/ORG	Group	pH			Saturated paste		N _{available} ^η			P _{total} ^λ	P _{available} ^φ	P _{inorganic} ^κ	N _{total} ^λ	C _{total} ^μ	C _{organic} ^ν
						H ₂ O	CaCl ₂		pH	E.C. (mS cm ⁻¹)	NO ₃ -N (ppm)	NH ₄ -N (ppm)							
67	PSP 145	NAT	1	MINERAL	CHEM	6.05					0.31	1.55		0.027	2.70	141.36	0.047	0.50	0.49
69	PSP 145	NAT	1	MINERAL	CHEM	7.53	6.75	0.23			0.29	1.45		0.033	3.09	233.31	0.040	0.48	0.43
189	PSP 149	NAT	1	LFH COMP	CHEM	5.18					3.67	18.35		0.050	18.06	190.61	0.183	3.27	3.26
167	PSP 149	NAT	1	LFH	Db	5.46					71.20	356.00		0.156	208.98	577.50	1.345	33.73	32.13
19	PSP 149	NAT	1	MINERAL	CHEM	5.19					0.58	2.90		0.022	1.40	68.50	0.039	0.42	0.42
17	PSP 149	NAT	1	MINERAL	CHEM	5.3					0.78	3.90		0.024	1.10	115.00	0.055	0.47	0.49
18	PSP 149	NAT	1	MINERAL	CHEM	5.51					0.86	4.30		0.045	4.10	327.75	0.065	0.47	0.48
20	PSP 149	NAT	1	MINERAL	CHEM	5.21					0.68	3.40		0.014	5.98	316.64	0.052	0.50	0.52
16	PSP 149	NAT	1	MINERAL	CHEM	6.05	5.67	0.10			0.28	1.40		0.031	5.41	244.42	0.034	0.34	0.35
199	PSP 164	NAT	1	LFH COMP	CHEM	4.88					9.26	46.30		0.035	29.37	39.69	0.450	10.86	10.80
179	PSP 164	NAT	1	LFH	Db	5.46					62.52	312.60		0.130	184.82	315.87	1.481	36.14	35.58
3	PSP 164	NAT	1	MINERAL	CHEM	5.25					0.24	1.20		0.006	0.30	12.00	0.020	0.23	0.23
1	PSP 164	NAT	1	MINERAL	CHEM	5.22					0.54	2.70		0.015	0.50	7.00	0.038	0.54	0.56
2	PSP 164	NAT	1	MINERAL	CHEM	5.82					0.27	1.35		0.010	0.70	32.00	0.023	0.40	0.40
4	PSP 164	NAT	1	MINERAL	CHEM	7.46	6.59	0.18			0.28	1.40		0.011	1.79	60.00	0.031	0.74	0.66
196	PSP 165	NAT	1	LFH COMP	CHEM	5.31					1.58	7.90		0.018	42.97	55.57	0.077	1.29	1.30
171	PSP 165	NAT	1	LFH	Db	5.28					64.34	321.70		0.111	322.72	452.02	1.425	41.27	41.01
39	PSP 165	NAT	1	MINERAL	CHEM	5.61					0.49	2.45		0.009	4.49	19.31	0.031	0.35	0.39
38	PSP 165	NAT	1	MINERAL	CHEM	5.48					0.29	1.45		0.008	1.29	18.81	0.020	0.21	0.14
37	PSP 165	NAT	1	MINERAL	CHEM	5.82					0.31	1.55		0.020	1.49	16.83	0.045	0.54	0.53
36	PSP 165	NAT	1	MINERAL	CHEM	7.18					0.21	1.05		0.025	2.00	120.78	0.037	0.58	0.55
35	PSP 165	NAT	1	MINERAL	CHEM	8.17					0.10	0.50		0.016	1.20	104.45	0.031	2.51	0.95
34	PSP 165	NAT	1	MINERAL	CHEM	8.63	7.31	0.20			0.14	0.70		0.017	1.80	126.72	0.025	1.77	0.41
181	PSP 173	NAT	1	LFH COMP	CHEM	5.59					6.04	30.20		0.059	38.17	134.62	0.379	8.22	8.09
172	PSP 173	NAT	1	LFH	Db	4.69					27.98	139.90		0.091	206.26	288.64	1.109	35.16	35.38
42	PSP 173	NAT	1	MINERAL	CHEM	5.48					0.99	4.95		0.035	16.70	125.47	0.049	0.49	0.48
40	PSP 173	NAT	1	MINERAL	CHEM	6.38					0.42	2.10		0.037	6.97	124.00	0.053	0.52	0.51
41	PSP 173	NAT	1	MINERAL	CHEM	8.41	7.37	0.15			0.10	0.50		0.028	2.09	177.76	0.029	3.89	0.35

Lab ID	Site	Type	F _{resc}	MIN/ORG	Group	pH			Saturated paste		N _{available} ^η			P _{total} ¹	P _{available} ^φ	P _{inorganic} ^κ	N _{total} ^λ	C _{total} ^μ	C _{organic} ^ν
						H ₂ O	CaCl ₂		pH	E.C. (mS cm ⁻¹)	NO ₃ -N (ppm)	NH ₄ -N (ppm)							
195	PSP 196	NAT	1	LFH COMP	CHEM	5.28					2.61	13.05		0.041	9.48	39.69	0.230	3.41	3.40
161	PSP 196	NAT	1	LFH	Db	5.68					44.79	223.95		0.112	183.93	330.00	1.179	37.52	36.97
73	PSP 196	NAT	1	MINERAL	CHEM	5.61					0.58	2.90		0.027	1.89	19.33	0.087	1.06	1.03
70	PSP 196	NAT	1	MINERAL	CHEM	5.28					1.03	5.15		0.024	0.90	37.60	0.057	0.59	0.58
71	PSP 196	NAT	1	MINERAL	CHEM	4.98					1.15	5.75		0.031	3.97	63.30	0.052	0.56	0.55
72	PSP 196	NAT	1	MINERAL	CHEM	5.1	4.2			0.05	1.10	5.50		0.032	9.06	99.94	0.045	0.53	0.53
187	PSP 199	NAT	1	LFH COMP	CHEM	5.36					1.29	6.45		0.044	25.35	201.50	0.112	2.19	2.19
164	PSP 199	NAT	1	LFH	Db	5.49					57.09	285.45		0.100	232.74	291.50	1.761	41.79	41.65
33	PSP 199	NAT	1	MINERAL	CHEM	5.18					0.73	3.65		0.038	23.70	261.09	0.058	0.76	0.73
32	PSP 199	NAT	1	MINERAL	CHEM	5.49					0.49	2.45		0.016	1.70	76.73	0.051	0.66	0.67
29	PSP 199	NAT	1	MINERAL	CHEM	6.68					0.24	1.20		0.018	2.89	96.53	0.040	0.55	0.52
31	PSP 199	NAT	1	MINERAL	CHEM	7.04	6.43			0.10	0.24	1.20		0.018	2.99	126.72	0.029	0.31	0.35
198	AUD 2	NAT	2	LFH COMP	CHEM	5.26					0.93	4.65		0.014	5.69	11.21	0.097	2.80	2.85
175	AUD 2	NAT	2	LFH	Db	5.78					4.76	23.80		0.058	27.54	59.68	0.606	24.89	24.59
30	AUD 2	NAT	2	MINERAL	CHEM	5.02					0.34	1.70		0.010	0.60	2.97	0.028	0.56	0.53
28	AUD 2	NAT	2	MINERAL	CHEM	6.72					1.52	7.60		0.016	2.57	20.30	0.039	0.99	0.90
26	AUD 2	NAT	2	MINERAL	CHEM	6.16					0.21	1.05		0.014	1.20	4.46	0.048	2.78	2.75
27	AUD 2	NAT	2	MINERAL	CHEM	8.11	6.79			0.18	0.10	0.50		0.012	0.70	45.05	0.059	4.71	4.07
183	AUD 3	NAT	2	LFH COMP	CHEM	5.08					1.49	7.45		0.028	19.17	45.30	0.163	4.44	4.41
173	AUD 3	NAT	2	LFH	Db	5.16					17.38	86.90		0.063	85.00	110.57	0.728	21.82	21.23
79	AUD 3	NAT	2	MINERAL	CHEM	7.38					0.28	1.40		0.017	18.33	52.33	0.022	0.34	0.34
81	AUD 3	NAT	2	MINERAL	CHEM	6.15					0.16	0.80		0.014	12.52	31.11	0.016	0.20	0.19
78	AUD 3	NAT	2	MINERAL	CHEM	5.54					0.17	0.85		0.008	2.48	7.07	0.015	0.42	0.42
80	AUD 3	NAT	2	MINERAL	CHEM	5.81	4.8			0.05	0.14	0.70		0.007	1.69	15.56	0.014	0.37	0.36
185	AUD 4	NAT	2	LFH COMP	CHEM	4.68					1.83	9.15		0.022	10.38	14.94	0.197	5.21	5.24
170	AUD 4	NAT	2	LFH	Db	4.46					13.94	69.70		0.061	54.50	64.30	0.992	32.13	32.19
47	AUD 4	NAT	2	MINERAL	CHEM	4.84					0.38	1.90		0.008	6.08	17.15	0.030	0.50	0.22
50	AUD 4	NAT	2	MINERAL	CHEM	5.83					0.23	1.15		0.022	36.06	86.38	0.020	0.20	0.06

Lab ID	Site	Type	P ^{resc}	MIN/ORG	Group	pH			Saturated paste		N _{available} ⁿ			P _{total} ¹	P _{available} ^o	P _{inorganic} ^k	N _{total} ^h	C _{total} ^u	C _{organic} ^v
						H ₂ O	CaCl ₂		pH	E.C. (mS cm ⁻¹)	NO ₃ -N (ppm)	NH ₄ -N (ppm)							
49	AUD 4	NAT	2	MINERAL	CHEM	6.01					0.18		0.90	0.010	9.58	30.57	0.013	0.09	0.08
51	AUD 4	NAT	2	MINERAL	CHEM	6.04					0.13		0.65	0.009	11.13	36.88	0.011	0.06	0.06
48	AUD 4	NAT	2	MINERAL	CHEM	6.71	5.8			0.05	0.22		1.10	0.009	5.57	41.74	0.011	0.06	0.05
193	PSP 161	NAT	2	LFH COMP	CHEM	5.06					2.09		10.45	0.016	17.92	37.83	0.120	3.20	3.15
168	PSP 161	NAT	2	LFH	Db	4.66					16.77		83.85	0.058	74.60	104.96	0.669	22.29	20.89
85	PSP 161	NAT	2	MINERAL	CHEM	5.55					0.29		1.45	0.007	8.38	16.03	0.019	0.23	0.22
84	PSP 161	NAT	2	MINERAL	CHEM	6.15					0.24		1.20	0.043	96.13	333.30	0.017	0.19	0.19
83	PSP 161	NAT	2	MINERAL	CHEM	6.48					0.22		1.10	0.020	37.18	108.43	0.014	0.10	0.09
82	PSP 161	NAT	2	MINERAL	CHEM	6.07	5.19			0.05	0.13		0.65	0.018	11.90	113.61	0.013	0.09	0.09
21	PSP 161	NAT	2	MINERAL	CHEM	6.62	6.05			0.08	0.19		0.95	0.021	3.10	95.54	0.031	0.42	0.39
197	PSP 163	NAT	2	LFH COMP	CHEM	4.9					0.61		3.05	0.005	2.96	2.33	0.050	1.27	1.26
178	PSP 163	NAT	2	LFH	Db	4.93					8.51		42.55	0.048	49.40	66.62	0.493	21.16	21.49
23	PSP 163	NAT	2	MINERAL	CHEM	5.43					0.11		0.55	0.017	55.57	111.38	0.015	0.16	0.15
24	PSP 163	NAT	2	MINERAL	CHEM	5.39					0.03		0.15	0.005	16.10	23.27	0.005	0.21	0.22
22	PSP 163	NAT	2	MINERAL	CHEM	5.72					0.05		0.25	0.004	13.05	28.71	0.009	0.04	0.04
25	PSP 163	NAT	2	MINERAL	CHEM	5.88	5.31			0.06	0.04		0.20	0.005	15.34	33.17	0.009	0.05	0.06
190	PSP 166	NAT	2	LFH COMP	CHEM	4.98					3.88		19.40	0.025	20.22	30.35	0.262	6.40	6.23
176	PSP 166	NAT	2	LFH	Db	5.67					24.76		123.80	0.095	196.51	299.53	1.186	34.44	33.82
59	PSP 166	NAT	2	MINERAL	CHEM	6.67					0.31		1.55	0.006	1.59	4.81	0.021	0.23	0.22
61	PSP 166	NAT	2	MINERAL	CHEM	5.69					0.29		1.45	0.008	2.50	15.38	0.023	0.25	0.25
58	PSP 166	NAT	2	MINERAL	CHEM	7.33					0.25		1.25	0.014	0.70	67.28	0.028	0.83	0.61
60	PSP 166	NAT	2	MINERAL	CHEM	7.58	7			0.21	0.19		0.95	0.017	2.87	73.05	0.032	0.97	0.65
56	PSP 166	NAT	2	MINERAL	CHEM	7.86	6.17			0.18	0.13		0.65	0.016	0.80	85.54	0.027	0.97	0.58
57	PSP 166	NAT	2	MINERAL	CHEM	8.44	7.23			0.10	0.27		1.35	0.007	0.40	35.08	0.012	0.45	0.22
184	PSP 171	NAT	2	LFH COMP	CHEM	5.08					1.59		7.95	0.027	25.00	69.58	0.139	4.91	4.93
180	PSP 171	NAT	2	LFH	Db	4.72					9.66		48.30	0.037	33.90	35.62	0.356	12.27	12.14
43	PSP 171	NAT	2	MINERAL	CHEM	5.62					0.20		1.00	0.025	66.17	177.76	0.020	0.28	0.25
44	PSP 171	NAT	2	MINERAL	CHEM	6.06					0.06		0.30	0.017	31.37	100.96	0.012	0.05	0.05

Lab ID	Site	Type	Presc.	MIN/ORG	Group	pH		Saturated paste		N _{available} ⁿ		P _{total} ^λ	P _{available} ^φ	P _{inorganic} ^κ	N _{total} ^λ	C _{total} ^μ	C _{organic} ^ν
						pH		E.C. (mS cm ⁻¹)	NO ₃ -N (ppm)	NH ₄ -N (ppm)							
						H ₂ O	CaCl ₂										
45	PSP 171	NAT	2	MINERAL	CHEM	6.32				0.06	0.30	0.014	13.15	80.38	0.011	0.08	0.07
46	PSP 171	NAT	2	MINERAL	CHEM	6.89	6.04		0.15	0.07	0.35	0.013	9.46	86.75	0.013	0.10	0.10
191	PSP 197	NAT	2	LFH COMP	CHEM	4.7				1.49	7.45	0.014	15.97	14.94	0.087	1.77	1.76
163	PSP 197	NAT	2	LFH	Db	5.52				38.19	190.95	0.079	222.86	269.50	0.785	22.28	21.79
77	PSP 197	NAT	2	MINERAL	CHEM	5				0.27	1.35	0.006	4.56	3.77	0.020	0.21	0.22
75	PSP 197	NAT	2	MINERAL	CHEM	5.5				0.36	1.80	0.069	175.10	655.49	0.023	0.29	0.28
74	PSP 197	NAT	2	MINERAL	CHEM	5.88				0.18	0.90	0.037	117.43	349.97	0.015	0.13	0.13
76	PSP 197	NAT	2	MINERAL	CHEM	6.02	4.92		0.07	0.16	0.80	0.033	79.52	227.76	0.021	0.20	0.21
188	SV 10	NAT	2	LFH COMP	CHEM	5.81				1.53	7.65	0.020	8.57	36.89	0.112	3.39	3.31
174	SV 10	NAT	2	LFH	Db	5.22				23.95	119.75	0.064	144.17	196.06	0.872	34.25	33.57
5	SV 10	NAT	2	MINERAL	CHEM	5.96				0.43	2.15	0.020	15.41	68.00	0.025	0.58	0.57
6	SV 10	NAT	2	MINERAL	CHEM	5.73				0.16	0.80	0.021	21.06	46.00	0.014	0.15	0.14
8	SV 10	NAT	2	MINERAL	CHEM	5.79				0.12	0.60	0.013	7.07	16.50	0.011	0.08	0.07
7	SV 10	NAT	2	MINERAL	CHEM	6.87	6.21		0.05	0.12	0.60	0.008	3.29	16.00	0.010	0.04	0.03
192	SV 2	NAT	2	LFH COMP	CHEM	5.4				1.86	9.30	0.025	19.90	36.42	0.248	6.84	6.66
166	SV 2	NAT	2	LFH	Db	5.55				17.49	87.45	0.064	118.82	198.00	0.752	23.11	22.93
65	SV 2	NAT	2	MINERAL	CHEM	4.4				0.23	1.15	0.006	3.47	1.90	0.026	0.31	0.31
64	SV 2	NAT	2	MINERAL	CHEM	5.68				0.15	0.75	0.032	94.40	283.31	0.019	0.18	0.17
62	SV 2	NAT	2	MINERAL	CHEM	6.23				0.13	0.65	0.031	62.77	244.42	0.020	0.20	0.20
63	SV 2	NAT	2	MINERAL	CHEM	6.5	5.88		0.07	0.13	0.65	0.035	43.06	283.31	0.023	0.30	0.30
155	90-1-5	REC	3	TS COMP	CHEM	7.52	7.09	7.94	423.34	0.52	2.60	0.031	3.28	209.00	0.125	3.08	2.73
96	90-1-5	REC	3	MINERAL	CHEM	7.58	7.15	8.77	475.31	0.34	1.70	0.029	2.19	188.87	0.186	5.25	4.80
97	90-1-5	REC	3	MINERAL	CHEM	7.36	7.13	8.49	445.53	0.41	2.05	0.033	1.70	183.32	0.168	5.34	4.60
145	90-2-1	REC	3	TS COMP	CHEM	7.33	6.96	8.49	433.13	3.58	17.90	0.050	6.04	405.52	0.367	7.15	6.81
112	90-2-1	REC	3	MINERAL	CHEM	6.83	6.63	7.49	339.17	0.84	4.20	0.047	0.60	411.07	0.214	5.90	5.63
113	90-2-1	REC	3	MINERAL	CHEM	7.02	6.83	8.03	385.01	1.02	5.10	0.042	0.70	355.52	0.272	6.18	5.79
140	90-2-2	REC	3	TS COMP	CHEM	7.6	7.09	9.19	495.19	1.31	6.55	0.048	5.89	211.09	0.137	2.21	2.01
130	90-2-2	REC	3	MINERAL	CHEM	8.16	7.47	8.66	527.87	0.21	1.05	0.089	0.30	755.48	0.056	1.48	0.74

Lab ID	Site	Type	Presc	MIN/ORG	Group	pH			Saturated paste		N _{available} ^h		P _{total} ⁱ	P _{available} ^g	P _{inorganic} ^k	N _{total} ^l	C _{total} ^m	C _{organic} ^v
						H ₂ O	CaCl ₂		pH	E.C. (mS cm ⁻¹)	NO ₃ -N (ppm)	NH ₄ -N (ppm)						
131	90-2-2	REC	3	MINERAL	CHEM	7.73	7.23	8.29	463.31		0.12	0.60	0.013	0.30	35.62	0.073	5.50	5.32
142	90-2-3	REC	3	TS COMP	CHEM	7.52	6.98	8.96	470.31		1.37	6.85	0.052	5.58	411.07	0.106	1.84	1.63
110	90-2-3	REC	3	MINERAL	CHEM	7.6	6.99	9.04	480.24		0.48	2.40	0.048	0.80	244.42	0.174	4.22	3.75
111	90-2-3	REC	3	MINERAL	CHEM	7.69	7.2	8.17	452.36		0.84	4.20	0.049	0.59	233.31	0.226	5.56	5.02
154	92-1-7	REC	3	TS COMP	CHEM	7.8	7.17	8.58	479.85		0.69	3.45	0.039	2.97	327.75	0.060	1.63	1.50
120	92-1-7	REC	3	MINERAL	CHEM	8.2	7.33	8.85	531.94		0.21	1.05	0.026	0.79	233.31	0.030	1.53	1.01
121	92-1-7	REC	3	MINERAL	CHEM	8.01	7.3	9.35	546.72		0.18	0.90	0.023	1.59	194.43	0.031	0.97	0.68
147	92-1-8	REC	3	TS COMP	CHEM	8.05	7.29	8.95	525.23		0.54	2.70	0.031	8.65	199.98	0.053	1.25	0.98
122	92-1-8	REC	3	MINERAL	CHEM	7.88	7.33	7.95	459.20		0.37	1.85	0.035	1.78	338.86	0.069	1.63	1.28
123	92-1-8	REC	3	MINERAL	CHEM	7.35	7.34	8.69	468.82		0.27	1.35	0.029	6.77	222.20	0.038	0.85	0.65
137	93-2-2	REC	4	TS COMP	CHEM	6.58	6.03	8.95	355.11		0.83	4.15	0.026	4.09	74.02	0.350	7.86	7.80
127	93-2-2	REC	4	MINERAL	CHEM	7.8	7.32	8.52	486.46		0.32	1.60	0.027	1.50	194.43	0.035	1.30	0.98
126	93-2-2	REC	4	MINERAL	CHEM	7.02	6.88	8.48	409.56		0.25	1.25	0.031	6.06	211.09	0.068	3.98	3.81
153	94-2-21	REC	4	TS COMP	CHEM	7.29	6.8	8.7	431.28		1.12	5.60	0.033	20.02	141.17	0.326	6.77	6.02
132	94-2-21	REC	4	MINERAL	CHEM	7.68	7.41	7.57	430.80		0.28	1.40	0.027	1.30	205.54	0.040	1.73	1.37
134	94-2-21	REC	4	MINERAL	CHEM	7.75	7.32	8.36	474.26		0.32	1.60	0.026	1.68	183.32	0.046	2.18	1.79
133	94-2-21	REC	4	MINERAL	CHEM	7.93	7.43	8.34	491.39		0.21	1.05	0.026	1.30	211.09	0.034	1.83	1.25
135	94-2-23	REC	4	TS COMP	CHEM	7.86	7.31	8.92	512.51		0.66	3.30	0.025	4.99	112.42	0.188	3.85	3.52
91	94-2-23	REC	4	MINERAL	CHEM	7.98	7.15	8.66	494.11		0.37	1.85	0.022	1.49	126.34	0.037	1.13	0.82
90	94-2-23	REC	4	MINERAL	CHEM	7.78	7.26	8.63	487.45		0.31	1.55	0.023	1.69	128.23	0.045	1.37	1.05
149	94-2-26A	REC		TS COMP	CHEM	7.5	7.03	9.23	486.65		1.01	5.05	0.028	7.90	82.04	0.295	6.53	6.32
138	94-2-26B	REC	4	TS COMP	CHEM	7.59	7.17	8.54	464.75		3.34	16.70	0.034	2.59	142.95	0.384	7.96	7.73
87	94-2-26B	REC	4	MINERAL	CHEM	7.6	6.93	8.8	463.48		0.24	1.20	0.020	3.59	100.89	0.031	0.72	0.68
86	94-2-26B	REC	4	MINERAL	CHEM	7.01	6.66	9.02	421.11		0.19	0.95	0.006	3.37	89.57	0.024	0.49	0.48
152	95-2-1	REC	4	TS COMP	CHEM	7.3	6.95	8.82	447.48		1.49	7.45	0.035	14.78	93.50	0.991	18.75	18.23
95	95-2-1	REC	4	MINERAL	CHEM	7.63	7.21	8.26	454.40		0.28	1.40	0.025	3.48	183.32	0.047	1.36	1.16
94	95-2-1	REC	4	MINERAL	CHEM	7.74	7.14	7.65	422.77		0.30	1.50	0.022	1.69	128.23	0.044	1.17	0.91
139	96-2-19	REC	4	TS COMP	CHEM	6.82	6.4	8.04	350.93		2.04	10.20	0.042	56.26	136.01	1.076	23.12	22.14

Lab ID	Site	Type	Presc.	MIN/ORG	Group	pH			Saturated paste		N _{available} ^η			P _{total} ¹	P _{available} ^φ	P _{inorganic} ^κ	N _{total} ^λ	C _{total} ^μ	C _{organic} ^ν
						H ₂ O	CaCl ₂	pH	E.C. (mS cm ⁻¹)	NO ₃ -N (ppm)	NH ₄ -N (ppm)								
124	96-2-19	REC	4	MINERAL	CHEM	7.24	7.22	8.32	434.91	0.48	2.40	0.037	3.26	255.53	0.067	1.48	1.31		
125	96-2-19	REC	4	MINERAL	CHEM	7.28	7.26	8.41	444.49	0.22	1.10	0.031	0.60	249.98	0.068	3.81	3.41		
141	SUN 25	REC	5	TS COMP	CHEM	6.7	5.75	6.29	242.32	0.71	3.55	0.010	6.82	20.36	0.070	1.33	1.33		
101	SUN 25	REC	5	MINERAL	CHEM	7.3	6.68	5.97	291.12	0.07	0.35	0.003	1.30	3.27	0.013	0.29	0.29		
100	SUN 25	REC	5	MINERAL	CHEM	7.57	6.79	8.01	411.72	0.09	0.45	0.004	0.00	1.41	0.013	0.47	0.46		
157	SUN 29	REC	5	TS COMP	CHEM	6.8	6.09	6.6	273.32	0.74	3.70	0.016	14.71	64.63	0.142	2.61	2.56		
107	SUN 29	REC	5	MINERAL	CHEM	7.68	6.73	8.9	460.01	0.09	0.45	0.003	0.00	3.27	0.012	0.27	0.26		
106	SUN 29	REC	5	MINERAL	CHEM	8.2	7.1	8.59	500.11	0.10	0.50	0.003	0.00	288.86	0.012	0.28	0.27		
148	SUN 38	REC	5	TS COMP	CHEM	7.37	6.99	8.22	423.46	0.51	2.55	0.020	10.98	135.67	0.086	2.44	2.17		
129	SUN 38	REC	5	MINERAL	CHEM	7.31	6.64	6.76	328.12	0.09	0.45	0.003	1.39	6.07	0.013	0.23	0.22		
128	SUN 38	REC	5	MINERAL	CHEM	7.54	6.79	6.81	348.65	0.10	0.50	0.004	0.90	6.54	0.012	0.24	0.23		
159	SUN 61	REC	5	TS COMP	CHEM	7.44	6.98	8.79	456.48	0.67	3.35	0.027	10.24	71.96	0.175	4.03	3.44		
118	SUN 61	REC	5	MINERAL	CHEM	7.39	6.97	8.74	450.18	0.65	3.25	0.025	2.30	74.72	0.159	3.97	3.74		
119	SUN 61	REC	5	MINERAL	CHEM	7.55	6.87	8.69	450.74	0.06	0.30	0.004	0.10	5.14	0.011	0.28	0.23		
150	SUN 77	REC	5	TS COMP	CHEM	4.41	4.32	4.25	80.97	1.21	6.05	0.023	10.00	111.83	0.149	4.05	4.06		
117	SUN 77	REC	5	MINERAL	CHEM	7.23	6.84	7.72	381.78	0.08	0.40	0.003	0.00	3.27	0.010	0.24	0.21		
116	SUN 77	REC	5	MINERAL	CHEM	7.66	6.96	8.45	450.50	0.08	0.40	0.004	0.00	6.07	0.010	0.28	0.23		
158	SUN 78	REC	5	TS COMP	CHEM	7.25	6.89	8.69	434.09	1.18	5.90	0.044	28.77	280.50	0.444	10.25	9.79		
108	SUN 78	REC	5	MINERAL	CHEM	6.59	5.63	5.08	188.48	0.05	0.25	0.002	0.00	0.00	0.009	0.11	0.11		
109	SUN 78	REC	5	MINERAL	CHEM	6.51	5.55	4.98	179.93	0.06	0.30	0.002	0.20	0.47	0.011	0.18	0.17		
146	92-2-5	REC	6	TS COMP	CHEM	7.79	7.27	9.15	518.19	0.58	2.90	0.027	3.88	103.58	0.121	3.29	3.00		
99	92-2-5	REC	6	MINERAL	CHEM	7.56	7.06	8.73	465.95	0.30	1.50	0.038	3.87	261.09	0.079	1.76	1.67		
98	92-2-5	REC	6	MINERAL	CHEM	7.94	7.03	8.37	467.20	0.12	0.60	0.004	0.00	5.66	0.014	0.34	0.33		
143	00-02-06	REC	6	TS COMP	CHEM	7.43	7.2	8.48	453.65	1.25	6.25	0.024	1.78	66.62	0.858	28.07	21.08		
102	00-02-06	REC	6	MINERAL	CHEM	7.83	7.17	7.26	407.58	0.27	1.35	0.027	1.69	194.43	0.034	1.49	1.12		
103	00-02-06	REC	6	MINERAL	CHEM	7.67	6.84	7.14	374.58	0.06	0.30	0.005	0.10	9.34	0.011	0.28	0.25		
151	94-2-13	REC	6	TS COMP	CHEM	7.49	7.1	8.54	454.15	0.60	3.00	0.034	8.15	249.98	0.105	2.69	2.38		
105	94-2-13	REC	6	MINERAL	CHEM	7.65	7.24	8.75	484.63	0.75	3.75	0.034	2.09	3.27	0.085	2.45	2.07		

Lab ID	Site	Type	Presc	MIN/ORG	Group	pH			Saturated paste		N _{available} ^η		P _{total} ^ι	P _{available} ^ο	P _{inorganic} ^κ	N _{total} ^λ	C _{total} ^μ	C _{organic} ^ν
						H ₂ O	CaCl ₂		pH	E.C. (mS cm ⁻¹)	NO ₃ -N (ppm)	NH ₄ -N (ppm)	(%)	PO ₄ -P (ppm)	(ppm)	(%)	(%)	(%)
104	94-2-13	REC	6	MINERAL	CHEM	7.41	6.72	7	348.57		0.05	0.25	0.003	0.00	9.34	0.013	0.28	0.26
136	94-2-31	REC	6	TS COMP	CHEM	7.55	7.14	8.66	466.83		0.75	3.75	0.030	3.19	128.14	0.330	7.66	7.23
115	94-2-31	REC	6	MINERAL	CHEM	7.87	7.24	8.95	509.96		0.18	0.90	0.018	2.39	56.50	0.030	0.63	0.55
114	94-2-31	REC	6	MINERAL	CHEM	7.78	6.92	8.74	470.54		0.11	0.55	0.005	0.60	4.67	0.010	0.22	0.20
156	96-2-16	REC	6	TS COMP	CHEM	7.51	7.04	8.71	460.50		1.09	5.45	0.033	3.70	132.00	0.329	7.03	6.65
92	96-2-16	REC	6	MINERAL	CHEM	7.91	7.22	8.78	501.43		0.31	1.55	0.028	2.00	205.54	0.039	1.28	0.94
93	96-2-16	REC	6	MINERAL	CHEM	7.78	6.96	8.29	448.89		0.08	0.40	0.003	0.10	8.01	0.012	0.30	0.26
144	97-2-8	REC	6	TS COMP	CHEM	7.59	7.25	8.54	469.93		1.35	6.75	0.032	1.89	98.08	0.817	23.63	21.04
88	97-2-8	REC	6	MINERAL	CHEM	7.97	7.1	8.81	498.53		0.23	1.15	0.023	1.31	211.09	0.043	2.42	1.85
89	97-2-8	REC	6	MINERAL	CHEM	7.66	6.78	6.29	326.67		0.10	0.50	0.003	0.30	3.77	0.010	0.18	0.16

APPENDIX D. SOIL PROFILE DESCRIPTIONS

TABLE D-1. List of abbreviations for soil profile descriptions.

1°	primary
2°	secondary
ab	abundant (roots) angular blocky (structure) abrupt (boundary)
aggreg	aggregate
Aw	<i>Populus tremuloides</i> (trembling aspen)
blk	blocky
C	clay
CL	clay loam
co	coarse
coar	coarse
d	dry
E	exped
fri	friable
grad	gradual
gran	granular
HC	heavy clay
I	inped
I/E	inped and exped
L	loam
LS	loamy sand
LS	lower subsoil (generally 50 – 100 cm)
m	moist
med	medium
mod	moderate
n/a	not applicable
obl	oblique
Pb	<i>Populus balsamifera</i> (balsam poplar)
Pj	<i>Pinus banksiana</i> (jackpine)
pl	plentiful
PM	peat/mineral mix
promin	prominent
ran	random
sab	sub angular blocky
SCL	sandy clay loam
Si	silt
SiCL	silty clay loam
SiL	silty loam
SiS	silty sand
sli	slight
Sw	<i>Picea glauca</i> (white spruce)
TS	topsoil (generally 0-20 cm)
US	upper subsoil (generally 20-50 cm)
v.	very
vert	vertical
vol.	volume

Site Description								
Site	PSP 141			Slope Position			Level	
Location	56°56'31"N		111°40'09"W	Slope Percent			-	
Soil Type	Natural - Fine			Slope Aspect			-	
PGM	Dover			% Stoniness to 1m			<1%	
LCCS Classification	2			Drainage Class		Moderately well		
CSSC Classification	Orthic Gray Luvisol			Effective Rooting Depth (cm)			65+	
Ecosite Classification	BM d1.1			Depth to Carbonates (cm)			75	
Site index	24(Aw)							
Soil Profile Description								
Horizon			LFH	Ahej	Aecj	AB	Bt	Cca
Depth			13-0	0-1	1-12	12-20	20-65	65+
Color			10YR2/1	10YR3/2	10YR6/2	10YR5/3	10YR5/3	-
Moisture			m	d	d	m	m	-
Texture			-	L	SiL	CL	CL	-
Structure	Primary	Grade	-	weak	strong	strong	mod.	-
		Size	-	fine	coarse	coarse	coarse	-
		Type	-	gran.	platy	blocky	blocky	-
		Consistence	-	v.friable	hard	v.firm	friable	-
	Secondary	Grade	-	-	mod.	-	strong	-
		Size	-	-	fine	-	fine	-
		Type	-	-	platy	-	blocky	-
		Consistence	-	-	friable	-	friable	-
Rooting	Abundance	Very fine	-	-	-	-	-	-
		Fine	ab	pl	pl	pl	few	-
		Medium	ab	pl	pl	pl	-	-
		Coarse	pl	few	few	few	-	-
	Orientation	Very fine	-	-	-	-	-	-
		Fine	ran/vert	vert	vert	vert	vert	-
		Medium	obl	obl	obl	obl	-	-
		Coarse	obl	obl	obl	obl	-	-
	Distribution	Very fine	-	-	-	-	-	-
		Fine	I/E	I/E	I/E	I/E	I/E	-
		Medium	I/E	I/E	I/E	I/E	-	-
		Coarse	I/E	I/E	I/E	I/E	-	-
Boundary	Sharpness		abrupt	-	clear	clear	abrupt	-
	Form		smooth	-	smooth	smooth	-	-
Mottles	Abundance		-	-	-	-	-	-
	Size		-	-	-	-	-	-
	Distinctness		-	-	-	-	-	-
	Color		-	-	-	-	-	-
Effervescence (10%)			x	x	x	x	x	strong

Site Description							
Site	PSP 145			Slope Position		Level	
Location	56°36'55"N		111°20'30"W	Slope Percent		-	
Soil Type	Natural - Fine			Slope Aspect		-	
PGM	Dover			% Stoniness to 1m		<1%	
LCCS Classification	2			Drainage Class	Imperfect		
CSSC Classification	Orthic Gray Luvisol†			Effective Rooting Depth (cm)		70+	
Ecosite Classification	BM d3.3			Depth to Carbonates (cm)		none @ 100	
Site index	15(Sw)						
Soil Profile Description							
Horizon			LFH	Ae	Btgj1†	Btgj2	Cgj
Depth			9.75-0	0-27	27-39	39-50	50-100+
Color			10YR2/1	10YR5/3	10YR5/3	10YR4/1	10YR5/2
Moisture			m	m	m	m	m
Texture			-	CL	CL	CL	CL
Structure	Primary	Grade	-	weak	strong	mod.	strong
		Size	-	coarse	fine	fine	fine
		Type	-	platy	blocky	blocky	sab
		Consistence	-	friable	friable	friable	friable
	Secondary	Grade	-	-	-	-	-
		Size	-	-	-	-	-
		Type	-	-	-	-	-
		Consistence	-	-	-	-	-
Rooting	Abundance	Very fine	-	-	-	-	-
		Fine	ab	pl	pl	pl	pl
		Medium	ab	pl	pl	-	-
		Coarse	ab	pl	pl	-	-
	Orientation	Very fine	-	-	-	-	-
		Fine	ran	vert/ran	vert/ran	vert	vert
		Medium	obl	obl	obl	-	-
		Coarse	obl	obl	obl	-	-
	Distribution	Very fine	-	-	-	-	-
		Fine	I/E	I/E	I/E	I/E	I/E
		Medium	I/E	I/E	I/E	-	-
		Coarse	I/E	I/E	I/E	-	-
Boundary	Sharpness		abrupt	clear	clear	gradual	-
	Form		smooth	smooth	smooth	smooth	-
Mottles	Abundance		-	-	common	common	common
	Size		-	-	fine	fine	fine
	Distinctness		-	-	faint	faint	faint
	Color		-	-	10YR5/6	10YR4/4	10YR4/4
Effervescence (10%)			x	x	x	x	x

† not a Gleyed gray luvisol because mottles are only faint in the B

‡ shinny ped surfaces due to water, pit is very wet, clay tight and heavy

Site Description								
Site	PSP 149			Slope Position			depression	
Location	57°01'07"N	111°55'36"W	Slope Percent			<3%		
Soil Type	Natural - Fine			Slope Aspect			-	
PGM	Dover			% Stoniness to 1m			3%	
LCCS Classification	2			Drainage Class	Imperfect			
CSSC Classification	Orthic Gray Luvisol			Effective Rooting Depth (cm)			70	
Ecosite Classification	BM d1.5			Depth to Carbonates (cm)			none @ 100	
Site index	23(Aw)							
Soil Profile Description								
Horizon			LFH	Ae1	Ae2	Bt1	Bt2	C
Depth			8.5-0	0-14	14-30	30-45	45-70	70-90+
Color			-	10YR6/2	10YR6/1	10YR5/3	10YR5/1	10YR4/2
Moisture			-	m	m	m	m	m
Texture			-	SiL	SiL	SiCL	SiCL	SiCL/SCL
Structure	Primary	Grade	-	strong	mod.	weak	mod.	-
		Size	-	coarse	coarse	med	coarse	-
		Type	-	platy	platy	sab	platy	-
		Consistence	-	v.friable	v.friable	v.friable	v.friable	-
	Secondary	Grade	-	strong	weak	strong	strong	-
		Size	-	fine	med.	fine	fine	-
		Type	-	platy	sab	blocky	platy & blocky	-
		Consistence	-	v.friable	v.friable	v.friable	v.friable	-
Rooting	Abundance	Very fine	-	-	-	-	-	-
		Fine	ab	pl	pl	pl	pl	-
		Medium	pl	pl	pl	few	few	-
		Coarse	few	-	-	-	-	-
	Orientation	Very fine	-	-	-	-	-	-
		Fine	ran	vert	vert	vert	vert	-
		Medium	obl	obl	obl	obl	obl	-
		Coarse	obl	-	-	-	-	-
	Distribution	Very fine	-	-	-	-	-	-
		Fine	I/E	I/E	I/E	I/E	I/E	-
		Medium	I/E	I/E	I/E	I/E	I/E	-
		Coarse	I/E	-	-	-	-	-
Boundary	Sharpness		clear	clear	grad	grad	grad	-
	Form		smooth	smooth	smooth	smooth	wavy	-
Mottles	Abundance		-	-	-	-	-	-
	Size		-	-	-	-	-	-
	Distinctness		-	-	-	-	-	-
	Color		-	-	-	-	-	-
Effervescence (10%)			x	x	x	x	x	x

Site Description									
Site	PSP 164			Slope Position			level		
Location	57°17'06"N		111°16'30"W	Slope Percent			-		
Soil Type	Natural-fine			Slope Aspect			-		
PGM	Kinosi			% Stoniness to 1m			4		
LCCS Classification	2/3			Drainage Class		Moderately well			
CSSC Classification	Solonetzic Gray Luvisol			Effective Rooting Depth (cm)			60		
Ecosite Classification	BM d2.5			Depth to Carbonates (cm)			105		
Site index	19(Sw) 23(Aw)								
Soil Profile Description									
Horizon			LFH	Ae	Aec	Btnj1 [†]	Btnj2 [†]	C	
Depth			8.5-0	0-15	15-28	28-40	40-60	60+	
Color			-	10YR5/2	5YR5/3	5YR6/4	5YR4/4	-	
Moisture			-	m	m	m	m	-	
Texture			-	LS	LS	SCL	CL	-	
Structure	Primary	Grade	-	weak	amorphous	weak	weak	-	
		Size	-	med		coarse	coarse	-	
		Type	-	platy		columnar	sab	-	
		Consistence	-	v.friable	hard	hard	firm	-	
	Secondary	Grade	-	-	-	-	mod	-	
		Size	-	-	-	-	fine	-	
		Type	-	-	-	-	sab	-	
		Consistence	-	-	-	-	-	-	
Rooting	Abundance	Very fine	ab	-	-	slight root matting between columns	-	-	
		Fine	ab	pl	few		-	-	
		Medium	ab	many	few		-	-	
		Coarse	-	-	-		-	-	
	Orientation	Very fine	ran	-	-		-	-	-
		Fine	ran	vert	vert		-	-	-
		Medium	obl	obl	obl		-	-	-
		Coarse	-	-	-		-	-	-
	Distribution	Very fine	I/E	-	-		-	-	-
		Fine	I/E	I/E	I/E		-	-	-
		Medium	I/E	I/E	I/E		-	-	-
		Coarse	-	-	-		-	-	-
Boundary	Sharpness		abrupt	clear	abrupt	-	abrupt	-	
	Form		smooth	smooth	smooth	-	smooth	-	
Mottles	Abundance		-	-	-	-	-	-	
	Size		-	-	-	-	-	-	
	Distinctness		-	-	-	-	-	-	
	Color		-	-	-	-	-	-	
Effervescence (10%)			x	x	x	x	x	-	

[†] clay skins, hardpan, columnar structure and other solonetzic features

Site Description									
Site	PSP 165			Slope Position				level	
Location	57°17'06"N		111°16'30"W		Slope Percent			-	
Soil Type	Natural-fine			Slope Aspect				-	
PGM	Kinosis			% Stoniness to 1m				0	
LCCS Classification	2/3			Drainage Class		Imperfect			
CSSC Classification	Orthic Gray Luvisol			Effective Rooting Depth (cm)				72	
Ecosite Classification	BM d2.4			Depth to Carbonates (cm)				72	
Site index	27(Aw) 7(Sw)								
Soil Profile Description									
Horizon			LFH	Ae	Aej	Bt1	Bt2	Cg1	Cg2
% Stoniness to 1m			0	0	gravel @ interface		2 by vol.	5	0
Depth			10.25-0	0-13	13-28	28-48	48-72	72-98	98+
Color			-	10YR6/2	10YR6/2	7.5YR5/3	7.5YR4/2	10YR3/4	10YR5/4
Moisture			-	m	m	m	m	m	m
Texture			-	LS	LS	CL-C	CL	SiL	SiL
Structure	Primary	Grade	-	weak	weak	weak	strong	v.weak coarse sab to amorphous	single grain
		Size	-	coarse	coarse	coarse	fine		
		Type	-	platy	platy	sab	ab		
		Consistence	-	v.friable	v.friable	firm	friable, crumblike		loose
	Secondary	Grade	-	weak	-	strong	-		-
		Size	-	fine	-	fine	-		-
		Type	-	platy	-	blocky	-		-
		Consistence	-	-	-	-	-		-
Rooting	Abundance	Very fine	ab	ab	-	ab	ab	-	-
		Fine	ab	ab	pl	-	-	few	-
		Medium	ab	many	few	-	few	-	-
		Coarse	-	-	-	-	few	-	-
	Orientation	Very fine	ran	ran/vert	-	vert	vert	-	-
		Fine	ran	ran/vert	vert	-	-	vert	-
		Medium	obl	obl	obl	-	vert	-	-
		Coarse	-	-	-	-	vert	-	-
	Distribution	Very fine	I/E	I/E	-	I/E, E in 1° structure	I/E, E in 1° structure	-	-
		Fine	I/E	I/E	I/E			I/E	-
		Medium	I/E	I/E	I/E			-	-
		Coarse	-	-	-			-	-
Boundary	Sharpness		abrupt	clear	abrupt	clear	abrupt	abrupt	-
	Form		smooth	wavy	wavy	wavy	smooth	smooth	-
Mottles	Abundance		-	-	many	-	-	Mottling but no sample taken	-
	Size		-	-	fine	-	-		-
	Distinctness		-	-	promin	-	-		-
	Color		-	-	10YR5/8	-	-		-
Effervescence (10%)			x	x	x	x	x	strong	x

Site Description								
Site	PSP 173		Slope Position			Level		
Location	57°08'34"N	111°38'02"W	Slope Percent			-		
Soil Type	Natural-fine		Slope Aspect			-		
PGM	Dover†		% Stoniness to 1m			<5		
LCCS Classification	2		Drainage Class	Moderately well				
CSSC Classification	Orthic Gray Luvisol		Effective Rooting Depth (cm)			64		
Ecosite Classification	BM d2.5		Depth to Carbonates (cm)			64		
Site index	17(Aw) 17(Sw)							
Soil Profile Description								
Horizon			LFH	Ahj	Ae	Bt	BC	IICk
Depth			9.5-0	0-6	6-20	20-45	45-64	64+
Color			10YR2/1	10YR3/3	10YR4/4	10YR4/3	10YR4/4	10YR4/4
Moisture			m	m	m	m	m	m
Texture			-	SiL	SiL	CL	SiCL	gravel
Structure	Primary	Grade	-	v.weak	mod-str/med- fine/platy	str	mod	single grain
		Size	-	fine		fine	fine	
		Type	-	gran		sab	sab	
		Consistence	-	v.friable		v.friable	v.friable	loose
	Secondary	Grade	-	-		Clay skins present	-	-
		Size	-	-			-	-
		Type	-	-			-	-
		Consistence	-	-			v.friable	-
Rooting	Abundance	Very fine	ab	ab	few	-	-	-
		Fine	ab	ab	few	few	-	-
		Medium	ab	few	few	few	few	-
		Coarse	ab	-	-	-	-	-
	Orientation	Very fine	ran	vert	vert	-	-	-
		Fine	ran	vert	vert	vert	-	-
		Medium	vert	vert	vert	vert	vert	-
		Coarse	obl	-	-	-	-	-
	Distribution	Very fine	I/E	I/E	I/E	-	-	-
		Fine	I/E	I/E	I/E	I/E	-	-
		Medium	I/E	I/E	I/E	I/E	I/E	-
		Coarse	I/E	I/E	-	-	-	-
Boundary	Sharpness		clear	clear	clear	diffuse	abrupt	-
	Form		wavy	smooth	smooth	smooth	smooth	-
Mottles	Abundance		-	-	-	-	-	-
	Size		-	-	-	-	-	-
	Distinctness		-	-	-	-	-	-
	Color		-	-	-	-	-	-
Effervescence (10%)			x	x	x	x	x	strong

[†] fluvial bed at 64 cm

Site Description								
Site	PSP 196			Slope Position			Level	
Location	56°23'56"N		111°25'40"W	Slope Percent			-	
Soil Type	Natural - Fine			Slope Aspect			-	
PGM	Kinosis			% Stoniness to 1m			2%	
LCCS Classification	2			Drainage Class		Moderately Well		
CSSC Classification	Orthic Gray Luvisol			Effective Rooting Depth (cm)			70+	
Ecosite Classification	BM d1.4			Depth to Carbonates (cm)			none @ 100	
Site index	18(Aw)							
Soil Profile Description								
Horizon			LFH	Ae1	Ae2	Bt1g	Bt2g	C
Depth			5.5-0	0-7	7-30	30-40	40-70	70+
Color			10YR2/1	10YR5/4	10YR5/2	10YR4/4	10YR4/1	-
Moisture			m	m	m	m	m	-
Texture			-	SiS	SiS	L/SiL	CL	-
Structure	Primary	Grade	-	weak	strong	strong	mod.	-
		Size	-	fine	med/fine	fine	med.	-
		Type	-	platy	platy	blocky	blocky	-
		Consistence	-	v.friable	v.friable	friable	firm	-
	Secondary	Grade	-	-	-	-	-	-
		Size	-	-	-	-	-	-
		Type	-	-	-	-	-	-
		Consistence	-	-	-	-	-	-
Rooting	Abundance	Very fine	-	-	-	-	-	-
		Fine	ab	ab	pl	pl	pl	-
		Medium	pl	pl	pl	pl	few	-
		Coarse	few	few	few	few	-	-
	Orientation	Very fine	-	-	-	-	-	-
		Fine	ran/vert	ran/vert	vert	vert	vert	-
		Medium	obl	obl	obl	obl	obl	-
		Coarse	obl	obl	obl	obl	-	-
	Distribution	Very fine	-	-	-	-	-	-
		Fine	I/E	I/E	I/E	I/E	I/E	-
		Medium	I/E	I/E	I/E	I/E	I/E	-
		Coarse	I/E	I/E	I/E	I/E	-	-
Boundary	Sharpness		abrupt	clear	clear	clear	-	-
	Form		smooth	smooth	smooth	smooth	-	-
Mottles	Abundance		-	-	-	few	few	-
	Size		-	-	-	fine	fine	-
	Distinctness		-	-	-	faint	faint	-
	Color		-	-	-	10YR4/6	10YR3/6	-
Effervescence (10%)			x	x	x	x	x	x

Site Description								
Site	PSP 199			Slope Position			Level	
Location	56°27'16"N		111°11'07"W	Slope Percent			-	
Soil Type	Natural - Fine			Slope Aspect			-	
PGM	Dover			% Stoniness to 1m			2%	
LCCS Classification	2			Drainage Class		Moderately well		
CSSC Classification	Orthic Gray Luvisol			Effective Rooting Depth (cm)			70+	
Ecosite Classification	BM d1.8			Depth to Carbonates (cm)			None @ 100	
Site index	19(Aw)							
Soil Profile Description								
Horizon			LFH	Ahej	Ae	Bt1gj	Bt2gj	C
Depth			9.5-0	0-2	2-17	17-45	45-60	60+
Color			10YR2/1	10YR2/1	10YR4/2	10YR6/2	10YR5/2	10YR5/2
Moisture			m	m	m	m	m	m
Texture			-	L	SL	C	CL	SCL
Structure	Primary	Grade	-	weak	mod.	strong	weak	stratified lacustrine material: structureless
		Size	-	fine	coarse	fine	coarse	
		Type	-	gran.	platy	blocky	platy	
		Consistence	-	v.friable	friable	firm	sli.firm	
	Secondary	Grade	-	-	mod.	-	strong	
		Size	-	-	med.	-	fine	
		Type	-	-	platy	-	blocky	
		Consistence	-	-	friable	-	sl.firm	
Rooting	Abundance	Very fine	-	-	-	-	-	-
		Fine	ab	ab	pl	pl	few	few
		Medium	ab	ab	few	few	few	few
		Coarse	pl	pl	few	few	few	few
	Orientation	Very fine	-	-	-	-	-	-
		Fine	ran	ran	vert	vert	vert	vert
		Medium	obl	obl	obl	obl	vert	vert
		Coarse	obl	obl	obl	obl	obl	obl
	Distribution	Very fine	-	-	-	-	-	-
		Fine	I/E	I/E	I/E	I/E	I/E	I/E
		Medium	I/E	I/E	I/E	I/E	I/E	I/E
		Coarse	I/E	I/E	I/E	I/E	I/E	I/E
Boundary	Sharpness		clear	-	gradual	gradual	-	-
	Form		smooth	-	smooth	smooth	-	-
Mottles	Abundance		-	-	-	few	common	-
	Size		-	-	-	fine	fine	-
	Distinctness		-	-	-	faint	faint	-
	Color		-	-	-	10YR5/2	10YR4/6	-
Effervescence (10%)			x	x	x	x	x	x

Site Description									
Site	SOIL/VEG 4			Slope Position			level		
Location	56°57'11"N		111°43'23"W	Slope Percent			-		
Soil Type	Natural-fine			Slope Aspect			-		
PGM	Dover			% Stoniness to 1m			2		
LCCS Classification	2			Drainage Class		Moderately well			
CSSC Classification	Orthic Gray Luvisol			Effective Rooting Depth (cm)			70		
Ecosite Classification	BM d1.1			Depth to Carbonates (cm)			None found		
Site index	22(Aw) <6(Pb)								
Soil Profile Description									
Horizon			LFH	Ae	AB	Btgj1	Btgj2	ICkg	IICg
Depth			9-0	0-13	13-20	20-45	45-70	70-85	85+
Color			-	10YR2/1	10YR6/3	10YR4/2	10YR4/2	10YR4/4	10YR4/3
Moisture			-	d	d	m	m	m	m
Texture			-	LS	LS	CL	CL	SiL	CL
Structure	Primary	Grade	10% fibric: old log	strong	strong	mod	strong	single grain	amorphous
		Size		co/med	coarse	fine	v.fine		
		Type		platy	platy	blocky	sab		
		Consistence		hard	v.hard	friable	friable		
	Secondary	Grade	-	-	-	strong	finer then Bt1+	-	-
		Size	-	-	-	fine		-	-
		Type	-	-	-	Sab		-	-
		Consistence	-	-	-	friable†		-	-
Rooting	Abundance	Very fine	-	-	-	-	-	-	-
		Fine	ab	pl	pl	few	few	-	-
		Medium	ab	ab	pl	pl	pl	-	-
		Coarse	ab	ab	pl	pl	pl	-	-
	Orientation	Very fine	-	-	-	-	-	-	-
		Fine	ran	vert	vert	vert	vert	-	-
		Medium	obl	obl	obl	obl	obl	-	-
		Coarse	obl	vert	obl	obl	obl	-	-
	Distribution	Very fine	-	-	-	-	-	-	-
		Fine	I/E	I/E	I/E	I/E	I/E	-	-
		Medium	I/E	I/E	I/E	I/E	I/E	-	-
		Coarse	I/E	I/E	I/E	I/E	I/E	-	-
Boundary	Sharpness		abrupt	clear	abrupt	diffuse	abrupt	abrupt	-
	Form		wavy	wavy	wavy	smooth	?	?	-
Mottles	Abundance		-	-	-	comm	comm	few	few
	Size		-	-	-	fine	v.fine	fine	fine
	Distinctness		-	-	-	distinct	faint	promin	promin
	Color		-	-	-	10YR5/6	10YR4/6	7.5YR3/4	7.5YR4/6
Effervescence (10%)			x	x	x	x	x	strong	x

† crumb-like structure with clay skins

‡ horizontal stratification but no clay skins

Site Description							
Site	SOIL/VEG 6			Slope Position		level	
Location	56°59'43"N	111°43'30"W	Slope Percent			-	
Soil Type	Natural-fine		Slope Aspect			-	
PGM	Dover		% Stoniness to 1m			<5	
LCCS Classification	2		Drainage Class	Moderately well			
CSSC Classification	Orthic Gray Luvisol		Effective Rooting Depth (cm)			70+	
Ecosite Classification	BM d3.1		Depth to Carbonates (cm)			70	
Site index†	15(Sw) 16(Pb)						
Soil Profile Description							
Horizon			LFH‡	Ae	AB	Bt	Ck
Depth			8.75-0	0-10	10-17	17-70	70+
Color			10YR2/1	10YR7/1	10YR5/3	10YR3/2	10YR4/3
Moisture			m	m	M	m	m
Texture			-	SL	SL	CL-L	CL
Structure	Primary	Grade	-	strong	weak	v.strong	weak
		Size	-	coarse	coarse	fine	coarse
		Type	-	platy	sab to platy	blocky	sab
		Consistence	-	strong	v.friable	v.friable	v.friable
	Secondary	Grade	-	strong	-	-	-
		Size	-	fine	-	-	-
		Type	-	platy	-	-	-
		Consistence	-	friable	-	-	-
Rooting	Abundance	Very fine	-	-	-	-	-
		Fine	ab	ab	Pl	pl	few
		Medium	ab	ab	Pl	pl	-
		Coarse	ab	ab	Pl	pl	few
	Orientation	Very fine	-	-	-	-	-
		Fine	ran	ran	vert	vert	vert
		Medium	obl	obl	obl	obl	-
		Coarse	obl	obl	obl	obl	obl
	Distribution	Very fine	-	-	-	-	-
		Fine	I/E	I/E	I/E	I/E	I/E
		Medium	I/E	I/E	I/E	I/E	-
		Coarse	I/E	I/E	I/E	I/E	I/E
Boundary	Sharpness		abrupt	clear	clear	abrupt	-
	Form		smooth	smooth	smooth	smooth	-
Mottles	Abundance		-	-	-	-	-
	Size		-	-	-	-	-
	Distinctness		-	-	-	-	-
	Color		-	-	-	-	-
Effervescence (10%)			x	x	x	x	strong

† Aspen poplar (*Populus tremuloides*) also present; † significant amount of white rot fungi

Site Description									
Site			AUDREY 2		Slope Position		crest		
Location			57°13'54"N	111°28'25"W	Slope Percent		3		
Soil Type			Natural-coarse		Slope Aspect		W		
PGM			glaciofluvial outwash sand		% Stoniness to 1m		40-59		
LCCS Classification			4M		Drainage Class	Moderately well			
CSSC Classification			Eluviated Eutric Brunisol		Effective Rooting Depth (cm)		40		
Ecosite Classification			BM a1.1→ BM a1.2		Depth to Carbonates (cm)		None @ 45		
Site index			19(Pj)						
Soil Profile Description									
Horizon				LFH	Ae1	Ae2	B	B+	C+
Inclusions				100%	100%	100%	30%	70%	100%
Depth				3-0	0-2	2-15	15-45	15-45	45+
Color				-	7.5YR5/4	5YR4/4	7.5YR4/4	10YR2/1	7.5YR2.5/1
Moisture				-	m	m	m	m	m
Texture				-	SL	SL	SCL	SCL	TS
Structure	Primary	Grade	-	weak/coarse/platy to v.weak/med/gran	weak	mod/str	mod/med/gran and str/med/gran	amorphous	
		Size	-		coarse	fine			
		Type	-		platy	gran			
		Consistence	-		v.friable	v.friable			friable
	Secondary	Grade	-		v.weak	-		-	
		Size	-		Med	-		-	
		Type	-		gran	-		-	
		Consistence	-		v.friable	v.friable		-	firm
Rooting	Abundance	Very fine	ab	ab	ab	-	-	-	
		Fine	ab	ab	ab	pl	-	pl	
		Medium	Pl	pl	pl	many	-	many	
		Coarse	Pl	pl	pl	-	-	-	
	Orientation	Very fine	vert	vert	vert	-	-	-	
		Fine	vert	vert	vert	vert	-	vert	
		Medium	obl	obl	obl	obl	-	obl	
		Coarse	obl	obl	obl	-	-	-	
	Distribution	Very fine	I/E	I/E	I/E	-	-	-	
		Fine	I/E	I/E	I/E	I/E	-	I/E	
		Medium	I/E	I/E	I/E	I/E	-	I/E	
		Coarse	I/E	I/E	I/E	-	-	-	
Boundary	Sharpness		abrupt	clear	gran	clear	-	-	
	Form		smooth	smooth	smooth	irreg	-	-	
Mottles	Abundance		-	-	-	-	-	-	
	Size		-	-	-	-	-	-	
	Distinctness		-	-	-	-	-	-	
	Color		-	-	-	-	-	-	
Effervescence (10%)				x	weak	weak	weak	x	x

[†] horizons comprised primarily of highly weathered, low-grade tar sand

Site Description								
Site	AUDREY 3			Slope Position			level	
Location	57°06'09"N		111°38'13"W	Slope Percent				0
Soil Type	Natural-coarse			Slope Aspect				-
PGM	glaciofluvial outwash sand			% Stoniness to 1m				3 (and gravel)
LCCS Classification	3			Drainage Class		Well drained		
CSSC Classification	Eluviated Eutric Brunisol			Effective Rooting Depth (cm)				80
Ecosite Classification	BM d1.9			Depth to Carbonates (cm)				None @ 100
Site index†	17(Pj) 16(Aw)							
Soil Profile Description								
Horizon			LFH	Ae	Bm1	Bm2	C	C
Inclusions			100%	100%	100%	100%	>95%	5%
Depth			7.5-0	0-16	16-50	50-70	70+	70+
Color			-	10YR5/4	10YR5/6	10YR4/6	2.5YR5/6	2.5YR3/2
Moisture			-	m	m	m	m	m
Texture			-	LS	S	S	S	-
Structure	Primary	Grade	-	single grain	single grain	single grain	single grain	oil sand inclusion in small pockets
		Size	-					
		Type	-					
		Consistence	-					
	Secondary	Grade	-	-	-	-	-	-
		Size	-	-	-	-	-	-
		Type	-	-	-	-	-	-
		Consistence	-	-	-	-	-	-
Rooting	Abundance	Very fine	-	-	-	-	-	-
		Fine	few	few	-	-	-	-
		Medium	ab	ab	med	med	med	-
		Coarse	pl	pl	few	few	few	-
	Orientation	Very fine	-	-	-	-	-	-
		Fine	ran	ran	-	-	-	-
		Medium	obl	obl	vert	vert	vert	-
		Coarse	obl	obl	obl	obl	obl	-
	Distribution	Very fine	-	-	-	-	-	-
		Fine	I/E	I/E	-	-	-	-
		Medium	I/E	I/E	I/E	I/E	I/E	-
		Coarse	I/E	I/E	I/E	I/E	I/E	-
Boundary	Sharpness		abrupt	clear	grad	grad	-	-
	Form		smooth	smooth	smooth	smooth	-	-
Mottles	Abundance		-	-	-	-	-	-
	Size		-	-	-	-	-	-
	Distinctness		-	-	-	-	-	-
	Color		-	-	-	-	-	-
Effervescence (10%)			x	x	x	x	x	x

[†] Balsam fir (*Abies balsamea*) also present

Site Description									
Site	AUDREY 4			Slope Position			level		
Location	56°58'08"N		111°29'33"W	Slope Percent			-		
Soil Type	Natural-coarse			Slope Aspect			-		
PGM	glaciofluvial outwash sands			% Stoniness to 1m			<1%		
LCCS Classification	3M			Drainage Class		Well			
CSSC Classification	Eluviated Dystric Brunisol			Effective Rooting Depth (cm)			>100		
Ecosite Classification	BM a1.3			Depth to Carbonates (cm)			None found		
Site index	14(Aw) 20(Pj)								
Soil Profile Description									
Horizon				LFH	Ae	Bm1	Bm2	BC	C
Depth				5-0	0-17	17-35	35-60	60-80	80+
Color				-	10YR6/1	7.5YR4/4	7.5YR4/6	10YR5/6	10YR5/3
Moisture				-	d	m	m	m	m
Texture				-	SL	LS	LS	LS	LS
Structure	Primary	Grade	-	weak	v.weak	single grain	single grain	single grain	
		Size	-	coarse	med				
		Type	-	platy	sab				
		Consistence	-	friable	friable				loose
	Secondary	Grade	-	-	-	-	-	-	-
		Size	-	-	-	-	-	-	-
		Type	-	-	-	-	-	-	-
		Consistence	-	-	-	-	-	-	-
Rooting	Abundance	Very fine	ab	ab	-	-	-	-	
		Fine	ab	-	pl	pl	few	few	
		Medium	-	-	-	-	-	-	
		Coarse	ab	ab	pl	pl	pl	pl	
	Orientation	Very fine	ran	ran/vert	-	-	-	-	
		Fine	ran	-	vert	vert	vert	vert	
		Medium	-	-	-	-	-	-	
		Coarse	vert/obl	obl	obl/vert	obl/vert	vert	vert	
	Distribution	Very fine	I/E	I/E	-	-	-	-	
		Fine	I/E	-	I/E	I/E	I/E	I/E	
		Medium	-	-	-	-	-	-	
Coarse		I/E	I/E	I/E	I/E	I/E	I/E		
Boundary	Sharpness		clear	abrupt	grad	grad	grad	-	
	Form		wavy	wavy	smooth	smooth	smooth	-	
Mottles	Abundance		-	-	-	-	-	-	
	Size		-	-	-	-	-	-	
	Distinctness		-	-	-	-	-	-	
	Color		-	-	-	-	-	-	
Effervescence (10%)			x	x	x	x	x	x	

Site Description										
Site	PSP 161			Slope Position		slight depression				
Location	57°12'52"N	111°30'18"W	Slope Percent		3					
Soil Type	Natural-coarse		Slope Aspect		W					
PGM	glaciofluvial outwash sands†		% Stoniness to 1m		0					
LCCS Classification	3		Drainage Class		Well					
CSSC Classification	Gleyed Eutric Brunisol†		Effective Rooting Depth (cm)			50				
Ecosite Classification	BM a1.1		Depth to Carbonates (cm)			None found				
Site index	15(Pj)									
Soil Profile Description										
Horizon		LFH	Ahej	Ae	Bm	Bmg	IC	IICgj	IICgj‡	
Inclusions		100%	100%	100%	100%	100%	100%	90%	10%	
Depth		6-0	0-6	6-18	18-36	36-50	50-90	90-120	90-120	
Color		-	10YR4/2	10YR5/3	7.5YR4/6	10YR5/6	10YR5/4	10YR5/2	10YR5/6	
Moisture		-	m	m	m	m	m	m	m	
Texture		-	SL	LS	LS	LS	LS	CL	S	
Structure	Primary	Grade	-	single grain	v.weak	single grain	single grain	single grain	Cannot tell structure	single grain
		Size	-		fine					
		Type	-		gran					
		Consistence	-	loose	v.friable	loose	loose	loose		
	Secondary	Grade	-	-	-	-	-	-	-	-
		Size	-	-	-	-	-	-	-	-
		Type	-	-	-	-	-	-	-	-
		Consistence	-	-	-	-	-	-	-	-
Rooting	Abundance	Very fine	ab	ab	-	-	-	-	-	-
		Fine	-	-	ab	pl	-	-	-	-
		Medium	ab	ab	ab	few	-	-	-	-
		Coarse	ab	ab	pl	-	-	-	-	-
	Orientation	Very fine	vert	vert	-	-	-	-	-	-
		Fine	-	-	vert	vert	-	-	-	-
		Medium	obl	obl	obl	vert	-	-	-	-
		Coarse	obl	obl	obl	-	-	-	-	-
	Distribution	Very fine	I/E	I/E	-	-	-	-	-	-
		Fine	-	-	I/E	I/E	-	-	-	-
		Medium	I/E	I/E	I/E	I/E	-	-	-	-
		Coarse	I/E	I/E	I/E	-	-	-	-	-
Boundary	Sharpness		abrupt	clear	abrupt	clear	grad	clear	-	-
	Form		smooth	smooth	smooth	smooth	smooth	smooth	-	-
Mottles	Abundance		-	-	-	-	few	-	-	many
	Size		-	-	-	-	fine	-	-	fine
	Distinctness		-	-	-	-	prom	-	-	faint
	Color		-	-	-	-	5YR3/4	-	-	10YR4/4
Effervescence (10%)		x	x	x	x	x	x	x	x	x

[†] fine textured lens at 90cm (IC); gleying in overlying B horizon [‡] IIC horizon present: 120+cm, 10YR5/6, coarse LS

Site Description										
Site	PSP 163			Slope Position				level		
Location	57°15'35"N		111°21'11"W		Slope Percent				-	
Soil Type	Natural-coarse			Slope Aspect				-		
PGM	glaciofluvial outwash sands			% Stoniness to 1m				0		
LCCS Classification	4M			Drainage Class		Moderately well				
CSSC Classification	Eluviated Dystric Brunisol			Effective Rooting Depth (cm)				70		
Ecosite Classification	BM a1.1→BM b1.1			Depth to Carbonates (cm)				None @ 110		
Site index	16(As) 13(Pj)									
Soil Profile Description										
Horizon			LFH	Ae1	Ae2	Bm1	Bm2†	BC	C	
Depth			3-0	0-4	4-15	15-33	33-50	50-60	60+	
Color			-	10YR5/2	10YR5/3	7.5YR5/8	10YR5/6	10YR6/4	10YR6/4	
Moisture			-	m	m	m	m	m	m	
Texture			-	S	S	S	S	S	S	
Structure	Primary	Grade	-	v.weak	v.weak	single grain	single grain	single grain	single grain	
		Size	-	med	coarse					
		Type	-	gran	platy					
		Consistence	-	v.friable	v.friable					
	Secondary	Grade	-	-	-	-	-	-	-	
		Size	-	-	-	-	-	-	-	
		Type	-	-	-	-	-	-	-	
		Consistence	-	-	-	-	-	-	-	
Rooting	Abundance	Very fine	-	-	-	-	-	-	-	
		Fine	ab	ab	ab	few	-	-	-	
		Medium	ab	ab	ab	many	few	few	few	
		Coarse	ab	ab	ab	-	-	-	-	
	Orientation	Very fine	-	-	-	-	-	-	-	
		Fine	ran	ran	ran	vert	-	-	-	
		Medium	ran	ran	ran	obl	vert	vert	vert	
		Coarse	obl	obl	obl	-	-	-	-	
	Distribution	Very fine	-	-	-	-	-	-	-	
		Fine	I/E	I/E	I/E	I/E	-	-	-	
		Medium	I/E	I/E	I/E	I/E	I/E	I/E	I/E	
		Coarse	I/E	I/E	I/E	-	-	-	-	
Boundary	Sharpness		clear	clear	abrupt	grad	grad	-	-	
	Form		smooth	smooth	wavy	wavy	smooth	-	-	
Mottles	Abundance		-	-	-	-	-	-	-	
	Size		-	-	-	-	-	-	-	
	Distinctness		-	-	-	-	-	-	-	
	Color		-	-	-	-	-	-	-	
Effervescence (10%)			x	x	x	x	x	x	x	

[†] inclusions of 10YR3/1 tar sand

Site Description										
Site	PSP 166					Slope Position			crest	
Location	57°19'53"N		111°12'39"W		Slope Percent			-		
Soil Type	Natural-coarse				Slope Aspect			-		
PGM	glaciofluvial outwash sands over glaciolacustrine				% Stoniness to 1m			4		
LCCS Classification	3				Drainage Class		Moderately well to imperfect			
CSSC Classification	Eluviated Dystric Brunisol				Effective Rooting Depth (cm)			70		
Ecosite Classification	BM d1.1				Depth to Carbonates (cm)			90		
Site index	18(Aw) 15(Sw)									
Soil Profile Description										
Horizon			LFH	Ae1	Ae2	Bmgj	BC	C1	C2	Cca
Depth			6.25-0	0-12	12-40	40-70	70-90	90-110	110-130	130+
Color			-	10YR5/2	10YR6/4	7.5YR4/3	7.5YR4/4	10YR3/4	10YR5/4	10YR4/4
Moisture			-	m	m	m	m	m	m	m
Texture			-	SL	LS	SCL	SCL	SCL	LS	SCL
Structure	Primary	Grade	-	weak	weak	med	amorphous			
		Size	-	coarse	coarse	coarse				
		Type	-	platy	platy	platy				
		Consistence	-	v.friable	v.friable	friable				
	Secondary	Grade	-	-	single grain	platy and stratified; breaks into layers	-	-	-	-
		Size	-	-			-	-	-	-
		Type	-	-			-	-	-	-
		Consistence	-	-			loose	-	-	-
Rooting	Abundance	Very fine	ab	-	-	-	-	-	-	-
		Fine	ab	pl	pl	pl	-	-	-	-
		Medium	-	-	-	-	-	-	-	-
		Coarse	ab	ab	ab	pl	-	-	-	-
	Orientation	Very fine	ran	-	-	-	-	-	-	-
		Fine	ran	vert	vert	vert	-	-	-	-
		Medium	-	-	-	-	-	-	-	-
		Coarse	obl	obl	obl	obl	-	-	-	-
	Distribution	Very fine	I/E	-	-	-	-	-	-	-
		Fine	I/E	I/E	I/E	I/E	-	-	-	-
		Medium	-	-	-	-	-	-	-	-
		Coarse	I/E	I/E	I/E	I/E	-	-	-	-
Boundary	Sharpness		abrupt	abrupt	abrupt	abrupt	clear	abrupt	abrupt	-
	Form		smooth	smooth	smooth	smooth	smooth	smooth	smooth	-
Mottles	Abundance		-	-	-	few	-	-	-	-
	Size		-	-	-	fine	-	-	-	-
	Distinctness		-	-	-	distinct	-	-	-	-
	Color		-	-	-	5YR4/4	-	-	-	-
Effervescence (10%)			x	x	x	x	weak	strong	strong	v.strong

Site Description									
Site	PSP 171		Slope Position			upper slope			
Location	57°30'17"N	111°26'14"W	Slope Percent			3			
Soil Type	Natural-coarse		Slope Aspect			N			
PGM	glaciofluvial outwash sand		% Stoniness to 1m			0			
LCCS Classification	4M		Drainage Class	Well drained					
CSSC Classification	Eluviated Eutric Brunisol		Effective Rooting Depth (cm)			60			
Ecosite Classification	BM a1.1		Depth to Carbonates (cm)			None @ 100			
Site index	13(Pj)								
Soil Profile Description									
Horizon		LFH	Aej	Bm1	Bm2	C	C		
Depth		3-0	0-2	2-40	40-60	60+	60+		
Inclusions		100%	100%	100%	100%	95%	5%		
Color		-	10YR3/3	10YR5/6	10YR5/4	10YR5/4	10YR5/6		
Moisture		-	m	m	m	m	m		
Texture		-	LS	LS	LS	LS	-		
Structure	Primary	Grade	-	single grain	single grain	single grain	single grain	oil sand pockets	
		Size	-						
		Type	-						
		Consistence	-						loose
	Secondary	Grade	-	-	-	-	-	-	-
		Size	-	-	-	-	-	-	-
		Type	-	-	-	-	-	-	-
		Consistence	-	-	-	-	-	-	-
Rooting	Abundance	Very fine	-	-	-	-	-	-	
		Fine	few	few	pl	few	-	-	
		Medium	pl	pl	pl	few	-	-	
		Coarse	-	-	pl	-	-	-	
	Orientation	Very fine	-	-	-	-	-	-	
		Fine	vert	vert	vert/obl	vert	-	-	
		Medium	obl	obl	vert/obl	vert	-	-	
		Coarse	-	-	obl	-	-	-	
	Distribution	Very fine	-	-	-	-	-	-	
		Fine	I/E	I/E	I/E	I/E	-	-	
		Medium	I/E	I/E	I/E	I/E	-	-	
		Coarse	-	-	I/E	-	-	-	
Boundary	Sharpness		clear	-	grad	grad	-	-	
	Form		smooth	-	smooth	smooth	-	-	
Mottles	Abundance		-	-	-	-	-	-	
	Size		-	-	-	-	-	-	
	Distinctness		-	-	-	-	-	-	
	Color		-	-	-	-	-	-	
Effervescence (10%)		x	x	x	x	x	x	x	

Site Description								
Site	PSP 197			Slope Position		mid slope		
Location	56°24'32"N	111°11'31"W	Slope Percent		4			
Soil Type	Natural - Coarse		Slope Aspect		NE			
PGM	glacial-outwash sand veneer		% Stoniness to 1m		0			
LCCS Classification	3/4		Drainage Class	Well				
CSSC Classification	Eluviated Dystric Brunisol		Effective Rooting Depth (cm)		80+			
Ecosite Classification	BM d1.4		Depth to Carbonates (cm)		none @ 80			
Site index	20(Aw)							
Soil Profile Description								
Horizon			LFH	Ae	Bm1	Bm2	C	C
Inclusion			100%	100%	100%	100%	95%	5%
Depth			7-0	0-14	14-37	37-50	50-80+	50-80+
Color			-	10YR6/3	7.5YR4/6	10YR5/6	10YR4/6	10YR3/4
Moisture			-	m	m	m	m	m
Texture			-	LS	LS	LS	LS	LS
Structure	Primary	Grade	-	weak	single grain	single grain	single grain	weak
		Size	-	coarse				-
		Type	-	platy				sab
		Consistence	-	v.friable	loose	loose	loose	stratified tar sand inclusion
	Secondary	Grade	-	-	-	-	-	
		Size	-	-	-	-	-	
		Type	-	-	-	-	-	
		Consistence	-	-	-	-	-	
Rooting	Abundance	Very fine	-	-	-	-	-	-
		Fine	pl	pl	pl	few	few	few
		Medium	pl	pl	pl	-	-	-
		Coarse	pl	pl	-	-	-	-
		Orientation	Very fine	-	-	-	-	-
	Fine		ran	ran	vert	vert	vert	vert
	Medium		obl	obl	obl&vert	-	-	-
	Coarse		obl	obl	-	-	-	-
	Distribution		Very fine	-	-	-	-	-
		Fine	I/E	I/E	I/E	I/E	I/E	I/E
		Medium	I/E	I/E	I/E	-	-	-
		Coarse	I/E	I/E	-	-	-	-
Boundary	Sharpness		abrupt	abrupt	clear	gradual	-	-
	Form		smooth	irregular	irregular	smooth	-	-
Mottles	Abundance		-	-	-	-	-	-
	Size		-	-	-	-	-	-
	Distinctness		-	-	-	-	-	-
	Color		-	-	-	-	-	-
Effervescence (10%)			x	x	x	x	x	x

Site Description									
Site	SOIL/VEG 2			Slope Position			level		
Location	57°00'20"N		111°27'07"W	Slope Percent			-		
Soil Type	Natural-fine			Slope Aspect			-		
PGM	erosional gullies and valleys [†]			% Stoniness to 1m			0		
LCCS Classification	2			Drainage Class		Well			
CSSC Classification	Eluviated Dystric Brunisol			Effective Rooting Depth (cm)			70		
Ecosite Classification	BM b3.3			Depth to Carbonates (cm)			None @100		
Site index	23(Sw) 17(Aw)								
Soil Profile Description									
Horizon				LFH	Ae1	Ae2	Bt1	Bt2	C
Depth				8.75-0	0-6	6-25	25-44	44-60	60+
Color				-	7.5YR4/2	7.5YR6/3	7.5YR5/6	7.5YR5/3	7.5YR5/3
Moisture				-	m	m	m	m	m
Texture				-	LS	LS	LS	LS	LS
Structure	Primary	Grade	-	v.weak	weak	weak	weak	single grain	
		Size	-	fine	med	coarse	coarse		
		Type	-	gran	platy	sab	sab		
		Consistence	-	v.friable	v.friable	friable	friable		loose
	Secondary	Grade	-	-	-	-	-	-	
		Size	-	-	-	-	-	-	
		Type	-	-	-	-	-	-	
		Consistence	-	-	-	-	-	-	
Rooting	Abundance	Very fine	-	-	-	-	-	-	
		Fine	ab	pl	pl	pl	pl	pl	
		Medium	pl	pl	pl	few	few	few	
		Coarse	few	-	-	-	-	-	
	Orientation	Very fine	-	-	-	-	-	-	
		Fine	ran	vert	vert	vert	vert	vert	
		Medium	obl	obl	obl	obl	obl	obl	
		Coarse	obl	-	-	-	-	-	
	Distribution	Very fine	-	-	-	-	-	-	
		Fine	I/E	I/E	I/E	I/E	I/E	I/E	
		Medium	I/E	I/E	I/E	I/E	I/E	I/E	
		Coarse	I/E	-	-	-	-	-	
Boundary	Sharpness		clear	clear	grad	grad	grad	-	
	Form		smooth	smooth	smooth	smooth	wavy	-	
Mottles	Abundance		-	-	-	-	-	-	
	Size		-	-	-	-	-	-	
	Distinctness		-	-	-	-	-	-	
	Color		-	-	-	-	-	-	
Effervescence (10%)			x	x	x	x	x	x	

[†] likely similar to the regional glaciofluvial outwash sands

Site Description								
Site		SOIL/VEG 10		Slope Position			level	
Location		57°04'25"N	111°35'37"W	Slope Percent			-	
Soil Type		Natural-coarse		Slope Aspect			-	
PGM		glaciofluvial outwash sands		% Stoniness to 1m			<1	
LCCS Classification		4M		Drainage Class		Well		
CSSC Classification		Eluviated Dystric Brunisol		Effective Rooting Depth (cm)			100+	
Ecosite Classification		BM a1.1		Depth to Carbonates (cm)			None @ 110	
Site index		18(Pj)						
Soil Profile Description								
Horizon			LFH	Aej	Bm1	Bm2	BC	C
Depth			2-0	0-18	18-38	38-70	70-110	110+
Color			-	10YR4/4	7.5YR4/6	7.5YR4/6	10YR5/6	10YR5/6
Moisture			-	d	m	m	m	m
Texture			-	LS	LS	LS	LS	LS
Structure	Primary	Grade	-	v.weak	v.weak	v.weak	single grain	single grain
		Size	-	med	coarse	coarse		
		Type	-	gran	sab	sab		
		Consistence	-	v.friable	friable	friable		
	Secondary	Grade	-	-	-	-	-	-
		Size	-	-	-	-	-	-
		Type	-	-	-	-	-	-
		Consistence	-	-	-	-	-	-
Rooting	Abundance	Very fine	ab	-	-	-	-	-
		Fine	ab	pl	few	few	-	-
		Medium	ab	ab	pl	pl	few	-
		Coarse	ab	ab	few	-	-	-
	Orientation	Very fine	ran	-	-	-	-	-
		Fine	ran	ran	vert	vert	-	-
		Medium	obl	obl	vert	vert	vert	-
		Coarse	obl	obl	vert	-	-	-
	Distribution	Very fine	I/E	-	-	-	-	-
		Fine	I/E	I/E	I/E	I/E	-	-
		Medium	I/E	I/E	I/E	I/E	I/E	-
		Coarse	I/E	I/E	I/E	-	-	-
Boundary	Sharpness		abrupt	clear	clear	clear	diffuse	-
	Form		smooth	smooth	smooth	smooth	smooth	-
Mottles	Abundance		-	-	-	-	-	-
	Size		-	-	-	-	-	-
	Distinctness		-	-	-	-	-	-
	Color		-	-	-	-	-	-
Effervescence (10%)			x	x	x	x	x	x

Site Description							
Site		90-1-5		Slope Position		upper slope	
Location		56°59'44"N	111°33'54"W	Slope Percent		12	
Soil Type		Reclaimed		Slope Aspect		N-NE	
Reclamation prescription		DP/OB		% Stoniness to 1m		10 by vol in US/gravel	
LCCS Classification		2		Drainage Class		Well to moderately well	
CSSC Classification		n/a		Effective Rooting Depth (cm)			>100
Dominant tree species		Sw Pb		Compaction			None to slight
Soil Profile Description							
Horizon			TS [†]	TS	TS	US	US
Depth			0-18	0-5	5-18	18-100	18-100
Color			10YR3/1	-	-	10YR2/1	10YR4/2
Moisture			d	-	-	d	d
Texture			PM(sand)	PM(sand)	PM(sand)	Peat	CL
Structure	Primary	Grade	-	mod	v.weak	-	weak
		Size	-	fine	fine	-	coarse
		Type	-	gran	gran	-	sab
		Consistence	-	v.friable	friable/loose	-	firm
	Secondary	Grade	-	-	-	-	-
		Size	-	-	-	-	-
		Type	-	-	-	-	-
		Consistence	-	-	-	-	-
Boundary	Sharpness		v.gradual	‡	-	-	-
	Form		not distinct	-	-	-	-
Mottles	Abundance		-	-	-	-	-
	Size		-	-	-	-	-
	Distinctness		-	-	-	-	-
	Color		-	-	-	-	-
Effervescence (10%)			x	x	x	x	x
Rooting at depth			0-8	8-90	-	-	-
Rooting	Abundance	Very fine	-	-	-	-	-
		Fine	ab	pl	-	-	-
		Medium	pl	few	-	-	-
		Coarse	-	-	-	-	-
	Orientation	Very fine	-	-	-	-	-
		Fine	vert	vert	-	-	-
		Medium	obl	obl	-	-	-
		Coarse	-	-	-	-	-
	Distribution	Very fine	-	-	-	-	-
		Fine	I/E	I/E	-	-	-
		Medium	I/E	I/E	-	-	-
		Coarse	-	-	-	-	-

† DP is dominantly peat throughout (peat-mineral mix)

‡ Unable to detect OB boundary

Site Description									
Site			90-2-1		Slope Position			upper slope	
Location			56°59'40"N	111°33'58"W	Slope Percent			12	
Soil Type			Reclaimed		Slope Aspect			NE	
Reclamation prescription			DP/OB		% Stoniness to 1m			3	
LCCS Classification			2		Drainage Class	Well to moderately well			
CSSC Classification			n/a		Effective Rooting Depth (cm)			90+	
Dominant tree species			Pj		Compaction			slight	
Soil Profile Description									
Horizon			LFH	TS	TS	US	US	US	US
Inclusions			100%	PM	mineral	100%	100%	100%	fibric†
Depth			2-0	0-25	0-25	75	25-100	25-100	25-100
Color			-	10YR2/2	10YR2/2	5Y3/1	2.5Y3/2	2.5Y3/1	10YR4/6
Moisture			-	d	d	d	d	d	d
Texture			-	PM	mineral	CL	L	L	-
Structure	Primary	Grade	pine needles and dead grass	v.weak	mod	not a distinct layer	weak	weak	-
		Size		fine	coarse		coarse	coarse	-
		Type		gran	gran		sab	sab	-
		Consistence		v.friable	friable		friable	friable	-
	Secondary	Grade	-	-	-	-	-	-	-
		Size	-	-	-	-	-	-	-
		Type	-	-	-	-	-	-	-
		Consistence	-	-	-	-	-	-	-
Boundary	Sharpness		v.gradual	-	-	-	-	-	-
	Form		-	-	-	-	-	-	-
Mottles	Abundance		-	-	-	-	-	-	-
	Size		-	-	-	-	-	-	-
	Distinctness		-	-	-	-	-	-	-
	Color		-	-	-	-	-	-	-
Effervescence (10%)			x	x	x	x	x	x	x
Rooting at depth			0-10	10-30	30-70	70-90	-	-	-
Rooting	Abundance	Very fine	ab	ab	-	-	-	-	-
		Fine	ab	ab	pl	few	-	-	-
		Medium	pl	-	-	-	-	-	-
		Coarse	few	-	-	-	-	-	-
	Orientation	Very fine	vert/ran	vert	-	-	-	-	-
		Fine	vert/ran	vert	vert	vert	-	-	-
		Medium	obl	-	-	-	-	-	-
		Coarse	obl	-	-	-	-	-	-
	Distribution	Very fine	I/E	I/E	-	-	-	-	-
		Fine	I/E	I/E	I/E	I/E	-	-	-
		Medium	I/E	-	-	-	-	-	-
		Coarse	I/E	-	-	-	-	-	-

[†] US has lots of undecomposed fibric material; white rot fungi to 100cm, small tar sand inclusions; not sure if OB was ever reached

Site Description							
Site	90-2-2			Slope Position		top	
Location	56°59'30"N		111°37'08"W	Slope Percent		<1	
Soil Type	Reclaimed		Slope Aspect		-		
Reclamation prescription	DP/OB		% Stoniness to 1m		2		
LCCS Classification	2		Drainage Class	Imperfectly			
CSSC Classification	n/a		Effective Rooting Depth (cm)		67		
Dominant tree species	Pj		Compaction		moderate		
Soil Profile Description							
Horizon			TS†	TS	TS	US	LS
Inclusions			55%	30%	<5%	100%	100%
Depth			0-21	0-21	0-21	21-75	75+
Color			Gley2 3/10	7.5YR4/6	-	2.5YR4/1	5Y2.5/1
Moisture			m	d	-	m	d
Texture			HC	CL-SCL‡	peat§	SiC	SC(cleanTS)
Structure	Primary	Grade	strong	weak/ coarse/ sab to amorphous	-	mod	amorphous to weak/ v.coarse/ sab
		Size	fine		-	coar/v.coar	
		Type	gran		-	ab	
		Consistence	v.friable		-	firm	
	Secondary	Grade	-		-	-	
		Size	-		-	-	
		Type	-		-	-	
		Consistence	-		-	-	hard
Boundary	Sharpness		clear	-	-	clear	-
	Form		distinct	-	-	distinct	-
Mottles	Abundance		-	-	-	10%area	-
	Size		-	-	-	coarse	-
	Distinctness		-	-	-	-	-
	Color		-	-	-	2.5YR3/6	-
Effervescence (10%)			v.weak	×	×	strong	×
Rooting at depth			0-19	19-30	30-75	75+	-
Rooting	Abundance	Very fine	-	-	-	-	-
		Fine	ab	pl	many	few	-
		Medium	-	-	-	-	-
		Coarse	-	-	-	-	-
	Orientation	Very fine	-	-	-	-	-
		Fine	ran	ran	vert	vert	-
		Medium	-	-	-	-	-
		Coarse	-	-	-	-	-
	Distribution	Very fine	-	-	-	-	-
		Fine	I/E	I/E	E	I/E	-
		Medium	-	-	-	-	-
		Coarse	-	-	-	-	-

†DP material was <10% sand; ‡roots were compressed/flattened; § lots of gravel

Site Description							
Site	90-2-3		Slope Position			mid slope	
Location	56°59'29"N	111°37'05"W	Slope Percent			14	
Soil Type	Reclaimed		Slope Aspect			S	
Reclamation prescription	DP/OB		% Stoniness to 1m			1 gravel	
LCCS Classification	4		Drainage Class	Well to moderately well			
CSSC Classification	n/a		Effective Rooting Depth (cm)			90+	
Dominant tree species	Pj		Compaction			slight	
Soil Profile Description							
Horizon		Peat [†]	-	-	-	-	
Inclusions		30%	30%	10%	15%	15%	
Depth		0-110	0-110	0-110	0-110	0-110	
Color		10YR2/1	10YR4/4	10YR6/4	10YR3/3 [‡]	10YR5/8 [‡]	
Moisture		d	d	d	d	d	
Texture		PM	SL	Si	SCL	SCL	
Structure	Primary	Grade	mesic/fibric material	single grain	amorphous	amorphous	
		Size					
		Type					
		Consistence					-
	Secondary	Grade	-	-	-	-	-
		Size	-	-	-	-	-
		Type	-	-	-	-	-
		Consistence	-	-	-	-	-
Boundary	Sharpness		no clear boundaries or horizons				
	Form						
Mottles	Abundance		-	-	-	-	-
	Size		-	-	-	-	-
	Distinctness		-	-	-	-	-
	Color		-	-	-	-	-
Effervescence (10%)		weak throughout profile					
Rooting at depth		0-9	9-60	60-90	-	-	
Rooting	Abundance	Very fine	-	-	-	-	-
		Fine	ab	pl	few	-	-
		Medium	ab	many	few	-	-
		Coarse	-	-	-	-	-
	Orientation	Very fine	-	-	-	-	-
		Fine	ran	vert/obl	vert	-	-
		Medium	obl	obl	vert	-	-
		Coarse	-	-	-	-	-
	Distribution	Very fine	-	-	-	-	-
		Fine	I/E	I/E	I/E	-	-
		Medium	I/E	I/E	I/E	-	-
		Coarse	-	-	-	-	-

[†] 2cm of LFH

[‡] very dry tar sand inclusions

Site Description								
Site			92-1-7		Slope Position		depression on top of slope	
Location			57°00'06"N	111°34'55"W	Slope Percent		-	
Soil Type			Reclaimed		Slope Aspect		-	
Reclamation prescription			DP/OB		% Stoniness to 1m		2	
LCCS Classification			3		Drainage Class		Moderately well	
CSSC Classification			n/a		Effective Rooting Depth (cm)			100
Dominant tree species			Aw Sw Pb		Compaction			slight
Soil Profile Description								
Horizon				LFH	TS	US/LS	US/LS	US/LS
Inclusions				-	100%	60%	5%	5%
Depth				1-0	0-9	9-120	9-120	9-120
Color				-	10YR3/3	10YR3/2	10YR5/8 10YR5/4	2.5YR5/6 5YR4/2
Moisture				-	m	m	m	m
Texture				-	L	SCL	LS	LS
Structure	Primary	Grade	-	mod	v.weak [†]	single grain	single grain	v.strong
		Size	-	fine	coarse			fine
		Type	-	gran	sab			blocky
		Consistence	-	v.friable	friable			loose
	Secondary	Grade	-	-	-	-	-	-
		Size	-	-	-	-	-	-
		Type	-	-	-	-	-	-
		Consistence	-	-	-	-	-	-
Boundary	Sharpness		-	gradual	-	-	-	-
	Form		-	wavy	-	-	-	-
Mottles	Abundance		-	-	-	-	-	-
	Size		-	-	-	-	-	-
	Distinctness		-	-	-	-	-	-
	Color		-	-	-	-	-	-
Effervescence (10%)				-	×	mod	mild	×
Rooting at depth				-	0-9	9-100	-	-
Rooting	Abundance	Very fine	-	-	pl	-	-	-
		Fine	-	pl	-	-	-	-
		Medium	-	pl	pl	-	-	-
		Coarse	-	-	-	-	-	-
	Orientation	Very fine	-	-	vert	-	-	-
		Fine	-	ran	-	-	-	-
		Medium	-	obl	vert	-	-	-
		Coarse	-	-	-	-	-	-
	Distribution	Very fine	-	-	I/E	-	-	-
		Fine	-	I/E	-	-	-	-
		Medium	-	I/E	I/E	-	-	-
		Coarse	-	-	-	-	-	-

[†] almost structureless

Site Description							
Site	92-1-8		Slope Position		mid slope		
Location	56°59'43"N	111°35'30"W	Slope Percent		6		
Soil Type	Reclaimed		Slope Aspect		SE		
Reclamation prescription	DP/OB		% Stoniness to 1m		2		
LCCS Classification	3		Drainage Class	Imperfectly			
CSSC Classification	n/a		Effective Rooting Depth (cm)		90+		
Dominant tree species	Aw Sw		Compaction		slight		
Soil Profile Description							
Horizon		TS	US/LS	US/LS	US/LS	US/LS	
Inclusions		100%	75%	5%	<5%	<5%	
Depth		0-6	6-120	6-120	6-120	6-120	
Color		10YR3/3	10YR3/2	2.5YR3/1	2.5YR5/3	7.5YR4/2	
Moisture		m	m	m	d	m	
Texture		SCL	SCL	C	LS	CL	
Structure	Primary	Grade	mod	mod	v.strong	v.strong	
		Size	fine	fine	fine	single grain	fine to v.fine
		Type	gran	sab	ab		blk
		Consistence	v.friable	v.friable	firm	loose	firm
	Secondary	Grade	-	-	-	-	-
		Size	-	-	-	-	-
		Type	-	-	-	-	-
		Consistence	-	-	-	-	-
Boundary	Sharpness		no visual boundaries				
	Form						
Mottles	Abundance		-	<5%area	-	-	-
	Size		-	<5mm	-	-	-
	Distinctness		-		-	-	-
	Color		-	2.5YR4/8	-	-	-
Effervescence (10%)		mild	mod	x	x	x	
Rooting at depth		0-6	6-90	-	-	-	
Rooting	Abundance	Very fine	-	-	-	-	-
		Fine	ab	pl	-	-	-
		Medium	pl	pl	-	-	-
		Coarse	-	-	-	-	-
	Orientation	Very fine	-	-	-	-	-
		Fine	ran	vert	-	-	-
		Medium	obl	vert/obl	-	-	-
		Coarse	-	-	-	-	-
	Distribution	Very fine	-	-	-	-	-
		Fine	I/E	I/E	-	-	-
		Medium	I/E	I/E	-	-	-
		Coarse	-	-	-	-	-

Site Description						
Site	93-2-2			Slope Position		upper slope
Location	56°59'49"N	111°35'30"W	Slope Percent		9	
Soil Type	Reclaimed		Slope Aspect		N-NW	
Reclamation prescription	H ₀ /2°/OB		% Stoniness to 1m		1 in mineral/5 in peat	
LCCS Classification	2		Drainage Class	Moderately well		
CSSC Classification	n/a		Effective Rooting Depth (cm)			100+
Dominant tree species	Sw		Compaction			None
Soil Profile Description						
Horizon			TS [†]	US	US	LS
Inclusions			100%	85%	5%	100%
Depth			0-28	28-70	28-70	70+
Color			10YR2/1	10YR3/2	10YR4/4	Gley1 3/10
Moisture			m	m	m	d
Texture			PM	SCL	LS	SCL
Structure	Primary	Grade	weak	weak	single grain	amorphous to weak/fine/gran when broken apart
		Size	fine	med-coarse		
		Type	gran	sab		
		Consistence	v.friable	friable		
	Secondary	Grade	-	-	-	
		Size	-	-	-	
		Type	-	-	-	
		Consistence	-	-	-	v.friable
Boundary	Sharpness		distinct	distinct	-	-
	Form		abrupt	abrupt	-	-
Mottles	Abundance		-	-	-	-
	Size		-	-	-	-
	Distinctness		-	-	-	-
	Color		-	-	-	-
Effervescence (10%)			×	mod	mod	×
Rooting at depth			0-28 [†]	28-70	-	70+
Rooting	Abundance	Very fine	ab	-	-	-
		Fine	-	many	-	many
		Medium	ab	pl	-	-
		Coarse	-	-	-	pl
	Orientation	Very fine	vert	-	-	-
		Fine	-	vert	-	vert
		Medium	obl/vert	obl/vert	-	-
		Coarse	-	-	-	vert
	Distribution	Very fine	I/E	-	-	-
		Fine	-	I/E	-	I
		Medium	I/E	I/E	-	-
		Coarse	-	-	-	E

† mineral material is a light coarse sand

† excellent rooting to depth

Site Description							
Site		94-2-21		Slope Position		upper slope	
Location		56°59'59"N	111°36'25"W	Slope Percent		9	
Soil Type		Reclaimed		Slope Aspect		S	
Reclamation prescription		H ₀ /2°/OB		% Stoniness to 1m		5 in peat/2 in mineral	
LCCS Classification		2		Drainage Class		Moderately well	
CSSC Classification		n/a		Effective Rooting Depth (cm)			80
Dominant tree species		Pj		Compaction			slight
Soil Profile Description							
Horizon			TS [†]	US [†]	US	US	
Inclusions			100%	90%	<5%	5-10%	
Depth			0-11	15-100	15-100	15-100	
Color			10YR2/1	10YR3/1	5YR5/3	5YR5/3	5YR4/6 [§]
Moisture			m	m	m	m	m
Texture			PM	SCL	C	CL	
Structure	Primary	Grade	weak	weak	strong	strong	
		Size	fine	coarse	med	coarse	
		Type	gran	sab	ab to blk	ab	
		Consistence	v.friable	v.friable	fri. to firm	firm	
	Secondary	Grade	-	-	-	-	
		Size	-	-	-	-	
		Type	-	-	-	-	
		Consistence	-	-	-	-	
Boundary	Sharpness		clear	-	-	-	
	Form		abrupt	-	-	-	
Mottles	Abundance		-	-	-	-	
	Size		-	-	-	-	
	Distinctness		-	-	-	-	
	Color		-	-	-	-	
Effervescence (10%)			×	mod	×	×	
Rooting at depth			0-11	11-80	-	-	
Rooting	Abundance	Very fine	-	-	-	-	
		Fine	ab	few	-	-	
		Medium	many	few	-	-	
		Coarse	-	-	-	-	
	Orientation	Very fine	-	-	-	-	
		Fine	vert	vert	-	-	
		Medium	obl	very	-	-	
		Coarse	-	-	-	-	
	Distribution	Very fine	-	-	-	-	
		Fine	I/E	I/E	-	-	
		Medium	I/E	I/E	-	-	
		Coarse	-	-	-	-	

[†] 0-15: mineral material is a light coarse sand; [‡] has some <5mm pink CL striations; [§] this color may be mottling but not sure

Site Description								
Site		94-2-23		Slope Position			upper slope	
Location		57°00'07"N	111°35'41"W	Slope Percent			4	
Soil Type		Reclaimed		Slope Aspect			S	
Reclamation prescription		H ₀ /2°/OB		% Stoniness to 1m			2 in mineral	
LCCS Classification		3		Drainage Class		Moderately well		
CSSC Classification		n/a		Effective Rooting Depth (cm)			80+	
Dominant tree species		Pj		Compaction			None	
Soil Profile Description								
Horizon			TS	US	US	US	US	LS
Inclusions			100%	90%	<5%	<5%	<5%	100%
Depth			0-9	9-110	9-110	9-110	9-110	110+
Color			10YR2/1	10YR3/3	10YR6/2	5YR5/3	5YR4/1	-
Moisture			d	d	d	d	d	-
Texture			PM	SCL	SiL	CL	CL	-
Structure	Primary	Grade	weak	weak	structure-less	strong	strong	overburden
		Size	fine	med		fine	v.fine	
		Type	gran	sab		blk	blk	
		Consistence	v.friable	friable to firm	loose	friable	friable	
	Secondary	Grade	-	-	-	-	-	-
		Size	-	-	-	-	-	-
		Type	-	-	-	-	-	-
		Consistence	-	-	-	-	-	-
Boundary	Sharpness		clear	clear	-	-	-	-
	Form		distinct	distinct	-	-	-	-
Mottles	Abundance		-	-	-	-	-	-
	Size		-	-	-	-	-	-
	Distinctness		-	-	-	-	-	-
	Color		-	-	-	-	-	-
Effervescence (10%)			mild	mild	×	×	×	×
Rooting at depth			0-9	9-80 [†]	-	-	-	-
Rooting	Abundance	Very fine	ab	-	-	-	-	-
		Fine	-	many	-	-	-	-
		Medium	-	few	-	-	-	-
		Coarse	pl	-	-	-	-	-
	Orientation	Very fine	vert/ran	-	-	-	-	-
		Fine	-	vert	-	-	-	-
		Medium	-	vert	-	-	-	-
		Coarse	obl	-	-	-	-	-
	Distribution	Very fine	I/E	-	-	-	-	-
		Fine	-	I/E	-	-	-	-
		Medium	-	I/E	-	-	-	-
		Coarse	I/E	-	-	-	-	-

[†] limited rooting in subsoil

Site Description							
Site		94-2-26B		Slope Position		slight depression	
Location		57°00'03"N	111°36'16"W	Slope Percent		-	
Soil Type		Reclaimed		Slope Aspect		-	
Reclamation prescription		H ₂ /2%/OB		% Stoniness to 1m		2 stones and gravel	
LCCS Classification		2		Drainage Class	Moderately well to imperfect		
CSSC Classification		n/a		Effective Rooting Depth (cm)			90+
Dominant tree species		Pj Pb		Compaction			None
Soil Profile Description							
Horizon			TS	US	LS	LS	LS
Inclusions			100%	100%	-	-	-
Depth			0-18	18-50	50-110+	50-110+	50-110+
Color			10YR2/1	5YR4/2	-	5YR5/2	5YR4/2
Moisture			m	m	-	m	m
Texture			PM	SCL	PM	S	CL
Structure	Primary	Grade	weak	weak	-	single grain	strong
		Size	fine	coarse	-		fine
		Type	gran	sab	-		sab
		Consistence	v.friable	friable	-	loose	v.friable
	Secondary	Grade	-	-	-	-	-
		Size	-	-	-	-	-
		Type	-	-	-	-	-
		Consistence	-	-	-	-	-
Boundary	Sharpness		distinct	-	-	-	-
	Form		clear	-	-	-	-
Mottles	Abundance		-	-	-	-	-
	Size		-	-	-	-	-
	Distinctness		-	-	-	-	-
	Color		-	-	-	-	-
Effervescence (10%)			x	x	x	x	x
Rooting at depth			0-18	18-80	-	-	-
Rooting	Abundance	Very fine	-	-	-	-	-
		Fine	ab	many	-	-	-
		Medium	pl	few	-	-	-
		Coarse	-	-	-	-	-
	Orientation	Very fine	-	-	-	-	-
		Fine	ran/vert	vert	-	-	-
		Medium	vert/obl	vert/obl	-	-	-
		Coarse	-	-	-	-	-
	Distribution	Very fine	-	-	-	-	-
		Fine	I/E	I/E	-	-	-
		Medium	I/E	I/E	-	-	-
		Coarse	-	-	-	-	-

Site Description									
Site			95-2-1		Slope Position			upper slope	
Location			57°00'04"N	111°34'28"W	Slope Percent			6	
Soil Type			Reclaimed		Slope Aspect			N-NW	
Reclamation prescription			H ₀ /2°/OB		% Stoniness to 1m			<1	
LCCS Classification			2		Drainage Class	Moderately well			
CSSC Classification			n/a		Effective Rooting Depth (cm)			90	
Dominant tree species			Aw Pb		Compaction			slight	
Soil Profile Description									
Horizon			TS	TS	US [†]	US	US	US	LS
Depth			0-6	6-20	20-73	20-73	20-73	20-73	73+
Color			10YR2/5	10YR2/5	5Y5/2	10YR4/3	2.5Y2.5/1	10YR5/2	10YR3/2
Moisture			m	m	m	m	m	m	m
Texture			PM	PM	CL	SCL	C	SCL	SCL
Structure	Primary	Grade	mod	weak	strong	weak	mod	no structure-tiger strip horizon	weak
		Size	fine	fine/med	med	med	fine		fine
		Type	gran	gran	ab	sab	blk-ab		sab
		Consistence	v.friable	v.friable	firm	friable	firm		friable
	Secondary	Grade	-	-	-	-	-		-
		Size	-	-	-	-	-		-
		Type	-	-	-	-	-		-
		Consistence	-	-	-	-	-		-
Boundary	Sharpness		abrupt	-	-	-	-	-	-
	Form		distinct	-	-	-	-	-	-
Mottles	Abundance		-	-	-	-	-	‡	-
	Size		-	-	-	-	-	-	-
	Distinctness		-	-	-	-	-	-	-
	Color		-	-	-	-	-	10YR4/6	-
Effervescence (10%)			x	x	x	mod	x	x	mod
Rooting at depth			0-5/6	5-20	20-90	-	-	-	-
Rooting	Abundance	Very fine	ab	-	-	-	-	-	-
		Fine	ab	ab	-	-	-	-	-
		Medium	ab	few	-	-	-	-	-
		Coarse	-	-	-	-	-	-	-
	Orientation	Very fine	vert	-	-	-	-	-	-
		Fine	vert	vert	-	-	-	-	-
		Medium	obl	obl	-	-	-	-	-
		Coarse	-	-	-	-	-	-	-
	Distribution	Very fine	I/E	-	-	-	-	-	-
		Fine	I/E	I/E	-	-	-	-	-
		Medium	I/E	I/E	-	-	-	-	-
		Coarse	-	-	-	-	-	-	-

[†] US is a mess of different material, "dog's breakfast"; ‡ mottles are tiger striped with SCL material

Site Description							
Site			96-2-19		Slope Position		upper slope
Location			57°00'07"N	111°34'56"W	Slope Percent		3
Soil Type			Reclaimed		Slope Aspect		N-NE
Reclamation prescription			H ₀ /2°/OB		% Stoniness to 1m		<1
LCCS Classification			3O		Drainage Class	Moderately well	
CSSC Classification			n/a		Effective Rooting Depth (cm)		80
Dominant tree species			Aw Sw Pj Pb		Compaction		slight
Soil Profile Description							
Horizon				TS		US	LS [†]
Depth				0-46		46-94	94+
Color				10YR2/1		5YR5/3	Gley1 2.5/0
Moisture				m		m	m
Texture				PM(sand)		CL-C	SCL
Structure	Primary	Grade	v.weak/ fine/ gran to single grain	strong		amorphous to weak/ coarse/ sab	
		Size		med			
		Type		blocky to ab			
		Consistence		firm			
	Secondary	Grade		-			
		Size		-			
		Type		-			
		Consistence		loose		-	friable
Boundary	Sharpness		distinct	distinct	-		
	Form		abrupt	abrupt	-		
Mottles	Abundance		-	-	-		
	Size		-	-	-		
	Distinctness		-	-	-		
	Color		-	-	-		
Effervescence (10%)				x	x	x	
Rooting at depth				0-46	46-80 [‡]	-	
Rooting	Abundance	Very fine	ab	few	-		
		Fine	ab	few	-		
		Medium	ab	few	-		
		Coarse	-	-	-		
	Orientation	Very fine	vert	vert	-		
		Fine	vert	vert	-		
		Medium	vert	vert	-		
		Coarse	-	-	-		
	Distribution	Very fine	I/E	I/E	-		
		Fine	I/E	I/E	-		
		Medium	I/E	I/E	-		
		Coarse	-	-	-		

[†] strong HC odour

[‡] some expd rooting in ab material in US

Site Description								
Site		SUNCOR 25		Slope Position		mid slope		
Location		56°59'54"N	111°27'38"W	Slope Percent		16		
Soil Type		Reclaimed		Slope Aspect		NE		
Reclamation prescription		H ₀ /TSS		% Stoniness to 1m		0		
LCCS Classification		3/4		Drainage Class	Well			
CSSC Classification		n/a		Effective Rooting Depth (cm)		80		
Dominant tree species		Jp JI		Compaction		None		
Soil Profile Description								
Horizon			LFH		TS		US/LS	
Depth			3-0		0-23		23+	
Color			-		10YR4/2		10YR5/3	
Moisture			-		d		d	
Texture			-		PM		LS	
Structure	Primary	Grade	L is moss dominated	v.weak		single grain		
		Size		fine				
		Type		granular				
		Consistence		friable to single grain		loose		
	Secondary	Grade	-	-		-		
		Size	-	-		-		
		Type	-	-		-		
		Consistence	-	-		-		
Boundary	Sharpness		clear		-		-	
	Form		abrupt		-		-	
Mottles	Abundance		-		-		-	
	Size		-		-		-	
	Distinctness		-		-		-	
	Color		-		-		-	
Effervescence (10%)			x		x		x	
Rooting at depth			0-23		30-60		-	
Rooting	Abundance	Very fine	abundant		few		-	
		Fine	abundant		few		-	
		Medium	-		-		-	
		Coarse	plentiful		plentiful		-	
	Orientation	Very fine	ran/vert		vertical		-	
		Fine	ran/vert		vertical		-	
		Medium	-		-		-	
		Coarse	oblique		oblique		-	
	Distribution	Very fine	I/E		I/E		-	
		Fine	I/E		I/E		-	
		Medium	-		-		-	
		Coarse	I/E		I/E		-	

Site Description								
Site		SUNCOR 29		Slope Position		mid slope		
Location		56°59'54"N	111°27'48"W	Slope Percent		27		
Soil Type		Reclaimed		Slope Aspect		N		
Reclamation prescription		H ₀ /TSS		% Stoniness to 1m		0		
LCCS Classification		3		Drainage Class	Very well			
CSSC Classification		n/a		Effective Rooting Depth (cm)		70		
Dominant tree species		Jp JI		Compaction		None		
Soil Profile Description								
Horizon			LFH		TS		US/LS	
Depth			3-0		0-21		21+	
Color			10YR2/1		10YR4/2		10YR5/3	
Moisture			d		d		d	
Texture			-		PM		LS	
Structure	Primary	Grade	L is dominantly moss	v.weak		single grain		
		Size		fine				
		Type		granular to single grain				
		Consistence		friable to loose				
	Secondary	Grade	-	-		-		
		Size	-	-		-		
		Type	-	-		-		
		Consistence	-	-		-		
Boundary	Sharpness		-	abrupt		-		
	Form		-	clear		-		
Mottles	Abundance		-	-		-		
	Size		-	-		-		
	Distinctness		-	-		-		
	Color		-	-		-		
Effervescence (10%)			- [†]	-		-		
Rooting at depth			0-20	20-30		30-70		
Rooting	Abundance	Very fine	abundant	plentiful		few		
		Fine	abundant	plentiful		few		
		Medium	-	-		-		
		Coarse	-	-		-		
	Orientation	Very fine	random	vert/obl		vertical		
		Fine	random	vert/obl		vertical		
		Medium	-	-		-		
		Coarse	-	-		-		
	Distribution	Very fine	I/E	I/E		I/E		
		Fine	I/E	I/E		I/E		
		Medium	-	-		-		
		Coarse	-	-		-		

[†] forgot to check for effervescence

Site Description						
Site		SUNCOR 38		Slope Position		mid slope
Location		56°59'21"N	111°29'02"W	Slope Percent		231
Soil Type		Reclaimed		Slope Aspect		S-SE
Reclamation prescription		H ₀ /TSS		% Stoniness to 1m		2 in PM
LCCS Classification		5		Drainage Class	Well	
CSSC Classification		n/a		Effective Rooting Depth (cm)		100
Dominant tree species		Aw		Compaction		none
Soil Profile Description						
Horizon			LFH [†]	TS(overlay) [‡]	TS [§]	US/LS
Depth			0-5	5-10	10-25	25+
Color			10YR4/2	10YR5/3	10YR3/2	10YR5/3
Moisture			d	d	d	d
Texture			-	LS	PM	LS
Structure	Primary	Grade	-	single grain	weak	single grain
		Size	-		fine-med	
		Type	-		granular	
		Consistence	-	loose	friable	loose
	Secondary	Grade	-	-	-	-
		Size	-	-	-	-
		Type	-	-	-	-
		Consistence	-	-	-	-
Boundary	Sharpness		-	clear	clear	-
	Form		-	abrupt	abrupt	-
Mottles	Abundance		-	-	-	-
	Size		-	-	-	-
	Distinctness		-	-	-	-
	Color		-	-	-	-
Effervescence (10%)			x	x	x	x
Rooting at depth			0-26	26-35	35+	0-100
Rooting	Abundance	Very fine	abundant	plentiful	-	-
		Fine	abundant	plentiful	few	-
		Medium	-	-	-	-
		Coarse	-	-	-	plentiful
	Orientation	Very fine	ran/vert	vertical	-	-
		Fine	ran/vert	vertical	vertical	-
		Medium	-	-	-	-
		Coarse	-	-	-	oblique
	Distribution	Very fine	I/E	I/E	-	-
		Fine	I/E	I/E	I/E	-
		Medium	-	-	-	-
		Coarse	-	-	-	I/E

[†] dense root matting

[‡] wind blown tailings sand overlay

[§] some firm mineral inclusions of the same color

Site Description				
Site	SUNCOR 61		Slope Position	mid to upper slope
Location	56°58'54"N	111°30'28"W	Slope Percent	19
Soil Type	Reclaimed		Slope Aspect	S
Reclamation prescription	H ₀ /TSS		% Stoniness to 1m	40 in PM
LCCS Classification	3		Drainage Class	Well
CSSC Classification	n/a		Effective Rooting Depth (cm)	50
Dominant tree species	Pj		Compaction	none
Soil Profile Description				
Horizon			TS	LS
Depth			0-43	43+
Color			10YR2/1	10YR5/3
Moisture			d	d
Texture			PM	LS
Structure	Primary	Grade	v.weak	single grain
		Size	fine	
		Type	granular	
		Consistence	v.friable	
	Secondary	Grade	-	-
		Size	-	-
		Type	-	-
		Consistence	-	-
Boundary	Sharpness		clear/abrupt	-
	Form		wavy	-
Mottles	Abundance		-	common
	Size		-	med
	Distinctness		-	distinct
	Color		-	10YR6/6 ⁺
Effervescence (10%)			x	x
Rooting at depth			0-14	14-43
Rooting	Abundance	Very fine	ab	pl
		Fine	ab	pl
		Medium	pl	few
		Coarse	-	-
	Orientation	Very fine	ran	vertical
		Fine	ran	vertical
		Medium	obl/lateral	vertical
		Coarse	-	-
	Distribution	Very fine	I/E	I/E
		Fine	I/E	I/E
		Medium	I/E	I/E
		Coarse	-	-

[†] mottles from 43-100cm

Site Description						
Site		SUNCOR 77		Slope Position		mid slope
Location		56°59'15"N	111°31'47"W	Slope Percent		14
Soil Type		Reclaimed		Slope Aspect		W
Reclamation prescription		H ₀ /TSS		% Stoniness to 1m		2 in PM
LCCS Classification		3		Drainage Class	Moderately well	
CSSC Classification		n/a		Effective Rooting Depth (cm)		30
Dominant tree species		Pl		Compaction		none
Soil Profile Description						
Horizon			TS	US/LS	US/LS	
Inclusions			100%	>95%	<5%	
Depth			0-11	11+	11+	
Color			10YR2/1	10YR5/3	10YR5/4	
Moisture			m	m	m	
Texture			LS	LS	LS (coarse)	
Structure	Primary	Grade	v.weak	single grain	-	
		Size	fine		-	
		Type	granular		-	
		Consistence	v.friable		loose	
	Secondary	Grade	-	-	-	
		Size	-	-	-	
		Type	-	-	-	
		Consistence	-	-	-	
Boundary	Sharpness		abrupt	-	-	
	Form		clear	-	-	
Mottles	Abundance		-	common	-	
	Size		-	med	-	
	Distinctness		-	distinct	-	
	Color		-	10YR5/6	-	
Effervescence (10%)			x	x	x	
Rooting at depth			0-11	11-30	-	
Rooting	Abundance	Very fine	ab	-	-	
		Fine	ab	pl	-	
		Medium	ab	few	-	
		Coarse	-	-	-	
	Orientation	Very fine	vert/ran	-	-	
		Fine	very/ran	vert	-	
		Medium	obl	obl	-	
		Coarse	-	-	-	
	Distribution	Very fine	I/E	-	-	
		Fine	I/E	I/E	-	
		Medium	I/E	I/E	-	
		Coarse	-	-	-	

Site Description						
Site		SUNCOR 78		Slope Position		mid slope
Location		56°58'41"N	111°27'51"W	Slope Percent		9
Soil Type		Reclaimed		Slope Aspect		S
Reclamation prescription		H ₀ /TSS		% Stoniness to 1m		5 by vol. gravel
LCCS Classification		3		Drainage Class	Well	
CSSC Classification		n/a		Effective Rooting Depth (cm)		50
Dominant tree species		Pj		Compaction		None
Soil Profile Description						
Horizon			TS	TS	US/LS	
Inclusions			10%	90%	100%	
Depth			0-17	0-17	17+	
Color			10YR3/2	10YR2/2	10YR5/4	
Moisture			d	d	m	
Texture			SCL	PM	LS	
Structure	Primary	Grade	strong	weak	single grain	
		Size	fine	fine		
		Type	sab	granular		
		Consistence	firm	v.friable		
	Secondary	Grade	-	-	-	
		Size	-	-	-	
		Type	-	-	-	
		Consistence	-	-	-	
Boundary	Sharpness		abrupt	-	-	
	Form		clear	-	-	
Mottles	Abundance		-	-	common [†]	few [†]
	Size		-	-	fine	fine
	Distinctness		-	-	distinct	distinct
	Color		-	-	10YR5/8	10YR5/8
Effervescence (10%)			mild	x	x	
Rooting at depth			0-24	24-50	-	
Rooting	Abundance	Very fine	-	-	-	
		Fine	abundant	abundant	-	
		Medium	-	-	-	
		Coarse	plentiful	few	-	
	Orientation	Very fine	-	-	-	
		Fine	ran/vert	vertical	-	
		Medium	-	-	-	
		Coarse	oblique	oblique	-	
	Distribution	Very fine	-	-	-	
		Fine	I/E	I/E	-	
		Medium	-	-	-	
		Coarse	I/E	I/E	-	

† 26-50cm

† 50+cm

Site Description							
Site	92-2-5			Slope Position		toe	
Location	57°03'58"N	111°39'48"W	Slope Percent			<2	
Soil Type	Reclaimed		Slope Aspect			-	
Reclamation prescription	H ₀ /2°/TSS		% Stoniness to 1m			<2	
LCCS Classification	3		Drainage Class	Well			
CSSC Classification	n/a		Effective Rooting Depth (cm)			58	
Dominant tree species	Pj		Compaction			None to slight	
Soil Profile Description							
Horizon			TS	US	US	US	LS
Inclusions			100%	10%	60%	30%	
Depth			0-15	15-50	15-50	15-50	50+
Color			10YR2/1	10YR2/1	2.5YR5/2	5YR4/1	5YR4/3 10YR5/3
Moisture			d	d	d	d	d
Texture			PM	PM	CL	SCL	LS
Structure	Primary	Grade	mod	coating	strong	weak	granular
		Size	fine	mineral	med/coar	med/coarse	
		Type	gran	aggre.	ab	sab	
		Consistence	friable	friable	firm	firm	
	Secondary	Grade	-	-	-	-	-
		Size	-	-	-	-	-
		Type	-	-	-	-	-
		Consistence	-	-	-	-	-
Boundary	Sharpness		diffuse	clear	-	-	-
	Form		wavy	abrupt	-	-	-
Mottles	Abundance		-	-	-	-	-
	Size		-	-	-	-	-
	Distinctness		-	-	-	-	-
	Color		-	-	-	-	-
Effervescence (10%)			x	x	strong [†]	x	x
Rooting at depth			0-15	15-30	30-50	-	-
Rooting	Abundance	Very fine	ab	pl	-	-	-
		Fine	-	pl	few	-	-
		Medium	pl	-	-	-	-
		Coarse	-	-	-	-	-
	Orientation	Very fine	ran	vert	-	-	-
		Fine	-	vert	vert	-	-
		Medium	obl	-	-	-	-
		Coarse	-	-	-	-	-
	Distribution	Very fine	I/E	I/E	-	-	-
		Fine	-	I/E	I/E	-	-
		Medium	I/E	-	-	-	-
		Coarse	-	-	-	-	-

† limestone inclusions causing strong effervescence

Site Description										
Site			94-2-13		Slope Position				mid slope	
Location			57°06'07"N	111°38'57"W	Slope Percent				7	
Soil Type			Reclaimed		Slope Aspect				N	
Reclamation prescription			H _o /2°/TSS		% Stoniness to 1m				2 in top 40cm	
LCCS Classification			2		Drainage Class		Moderately well			
CSSC Classification			n/a		Effective Rooting Depth (cm)				59	
Dominant tree species			Aw		Compaction				None	
Soil Profile Description										
Horizon			TS	US [†]	US	US	US	US	LS	LS [‡]
Inclusions			100%	65%	10%	10%	10%	5%	100%	100%
Depth			0-10	10-40	10-40	10-40	10-40	10-40	40+	59-61
Color			10YR2/1	10YR3/2	2.5Y5/3	10YR5/6	5Y5/3	5Y3/1	10YR5/3	-
Moisture			m	d	d	d	d	d	d	-
Texture			PM	SCL	Si	-	CL	C	LS	-
Structure	Primary	Grade	mod	v.weak	weak	weak	mod	mod	single grain	-
		Size	weak	fine	coarse	coarse	fine-med	fine		-
		Type	gran	sab	platy-sab	platy-sab	ab	ab		-
		Consistence	v.friable	friable	v.friable	v.friable	firm	firm		loose
	Secondary	Grade	-	-	-	-	-	-	-	-
		Size	-	-	-	-	-	-	-	-
		Type	-	-	-	-	-	-	-	-
		Consistence	-	-	-	-	-	-	-	-
Boundary	Sharpness		clear	abrupt	-	-	-	-	-	-
	Form		distinct	distinct	-	-	-	-	-	-
Mottles	Abundance		-	-	-	-	-	-	-	-
	Size		-	-	-	-	-	-	-	-
	Distinctness		-	-	-	-	-	-	-	-
	Color		-	-	-	-	-	-	-	-
Effervescence (10%)			x	x	x	x	x	x	x	x
Rooting at depth			0-10	10-40	-	-	-	-	-	-
Rooting	Abundance	Very fine	ab	-	-	-	-	-	-	-
		Fine	ab	-	-	-	-	-	-	-
		Medium	pl	-	-	-	-	-	-	-
		Coarse	-	-	-	-	-	-	-	-
	Orientation	Very fine	vert/ran	-	-	-	-	-	-	-
		Fine	vert/ran	-	-	-	-	-	-	-
		Medium	obl	-	-	-	-	-	-	-
		Coarse	-	-	-	-	-	-	-	-
	Distribution	Very fine	I/E	-	-	-	-	-	-	-
		Fine	I/E	-	-	-	-	-	-	-
		Medium	I/E	-	-	-	-	-	-	-
		Coarse	-	-	-	-	-	-	-	-

[†] several different minral materials with fibric peat and wood inclusions

[‡] layers of oil and TSS (has HC odour) one side of the pit creating a perched water table

Site Description								
Site			94-2-31		Slope Position		mid slope	
Location			57°06'04"N	111°38'56"W	Slope Percent		8	
Soil Type			Reclaimed		Slope Aspect		N-NE	
Reclamation prescription			H ₀ /2°/TSS		% Stoniness to 1m		0	
LCCS Classification			2/3		Drainage Class	Moderately well		
CSSC Classification			n/a		Effective Rooting Depth (cm)		80	
Dominant tree species			Aw		Compaction		slight	
Soil Profile Description								
Horizon			TS	US	US [†]	US	US [†]	LS [§]
Inclusions			100%	5%	75%	10%	10%	100%
Depth			0-20	20-70	20-70	20-70	20-70	70+
Color			10YR2/1	10YR5/3	10YR4/2	5YR5/3	5Y6/2	10YR5/3
Moisture			m	m	m	m	m	d
Texture			PM	CL	CL	CL	Si	LS
Structure	Primary	Grade	v.weak	strong	mod	strong	mod	single grain
		Size	fine	fine	med	fine	fine/med	
		Type	gran	ab	sab	ab	platy	
		Consistence	v.friable	sli.firm	friable	friable	v.friable	
	Secondary	Grade	-	-	-	-	-	-
		Size	-	-	-	-	-	-
		Type	-	-	-	-	-	-
		Consistence	-	-	-	-	-	-
Boundary	Sharpness		distinct	clear	-	-	-	-
	Form		abrupt	abrupt	-	-	-	-
Mottles	Abundance		-	many	-	-	-	-
	Size		-	fine	-	-	-	-
	Distinctness		-	promin	-	-	-	-
	Color		-	10YR5/8	-	-	-	-
Effervescence (10%)			x	x	x	x	x	x
Rooting at depth			0-25	25-70	-	-	-	70-80
Rooting	Abundance	Very fine	ab	pl	-	-	-	-
		Fine	ab	pl	-	-	-	few
		Medium	pl	few	-	-	-	-
		Coarse	-	-	-	-	-	-
	Orientation	Very fine	ran	vert	-	-	-	-
		Fine	ran	vert	-	-	-	vert
		Medium	obl	vert	-	-	-	-
		Coarse	-	-	-	-	-	-
	Distribution	Very fine	I/E	I/E	-	-	-	-
		Fine	I/E	I/E	-	-	-	I/E
		Medium	I/E	I/E	-	-	-	-
		Coarse	-	-	-	-	-	-

[†] contains <1% peat inclusions

[‡] looks like a remnant Ae horizon in 2° material despite the texture [§] moist to 84cm, then dry

Site Description							
Site		96-2-16		Slope Position		mid to lower slope	
Location		57°03'53"N	111°39'42"W	Slope Percent		7	
Soil Type		Reclaimed		Slope Aspect		W	
Reclamation prescription		H ₀ /2°/TSS		% Stoniness to 1m		<2	
LCCS Classification		3		Drainage Class	Well		
CSSC Classification		n/a		Effective Rooting Depth (cm)			60
Dominant tree species		Aw Sw		Compaction			None
Soil Profile Description							
Horizon			TS†	US	US	US	LS
Inclusions			100%	30%	60%	10%	100%
Depth			0-15‡	15-50	15-50	15-50	50+
Color			10YR2/2	5YR4/3	10YR3/2	10YR2/2	10YR5/3
Moisture			d	m	d	d	d
Texture			PM	CL	SCL	PM	LS
Structure	Primary	Grade	weak	weak	weak	weak	single grain
		Size	fine	coarse	med	fine	
		Type	granular	sab	sab	granular	
		Consistence	friable	friable	friable	friable	
	Secondary	Grade	-	-	-	-	-
		Size	-	-	-	-	-
		Type	-	-	-	-	-
		Consistence	-	-	-	-	-
Boundary	Sharpness		abrupt	abrupt	-	-	-
	Form		clear	clear	-	-	-
Mottles	Abundance		-	-	-	-	-
	Size		-	-	-	-	-
	Distinctness		-	-	-	-	-
	Color		-	-	-	-	-
Effervescence (10%)			x	x	x	x	x
Rooting at depth			0-15	15-50	-	-	-
Rooting	Abundance	Very fine	abundant	-	-	-	-
		Fine	abundant	few	-	-	-
		Medium	-	-	-	-	-
		Coarse	-	-	-	-	-
	Orientation	Very fine	random	-	-	-	-
		Fine	random	vert/ran	-	-	-
		Medium	-	-	-	-	-
		Coarse	-	-	-	-	-
	Distribution	Very fine	I/E	-	-	-	-
		Fine	I/E	I/E	-	-	-
		Medium	-	-	-	-	-
		Coarse	-	-	-	-	-

[†] minor inclusions of upper subsoil material

[‡] horizon thickness ranges from 0-20cm

Site Description						
Site		97-2-8		Slope Position		mid slope
Location		57°04'57"N	111°40'15"W	Slope Percent		5
Soil Type		Reclaimed		Slope Aspect		SW
Reclamation prescription		H ₀ /2°/TSS		% Stoniness to 1m		5 by vol. in TS
LCCS Classification		3		Drainage Class	Rapid to well	
CSSC Classification		n/a		Effective Rooting Depth (cm)		51
Dominant tree species		Pj		Compaction		slight
Soil Profile Description						
Horizon			TS	US	LS	
Depth			0-19	19-50	50+	
Color			10YR3/2	10YR3/2	10YR5/3	
Moisture			d	d	d	
Texture			PM	SCL	LS	
Structure	Primary	Grade	weak	weak	single grain	
		Size	fine	med/coarse		
		Type	granular	sab		
		Consistence	friable	firm		
	Secondary	Grade	-	-	-	
		Size	-	-	-	
		Type	-	-	-	
		Consistence	-	-	-	
Boundary	Sharpness		abrupt	abrupt	-	
	Form		clear	clear	-	
Mottles	Abundance		-	-	-	
	Size		-	-	-	
	Distinctness		-	-	-	
	Color		-	-	-	
Effervescence (10%)			×	weak	×	
Rooting at depth			0-5	5-18	18-50	
Rooting	Abundance	Very fine	abundant	-	-	
		Fine	plentiful	plentiful	few	
		Medium	-	-	-	
		Coarse	-	-	-	
	Orientation	Very fine	random	-	-	
		Fine	oblique	vertical	vertical	
		Medium	-	-	-	
		Coarse	-	-	-	
	Distribution	Very fine	I/E	-	-	
		Fine	I/E	I/E	I/E ⁺	
		Medium	-	-	-	
		Coarse	-	-	-	

[†] evidence of exped rooting

Site Description								
Site		00-02-06		Slope Position		upper slope		
Location		57°05'53"N	111°40'52"W	Slope Percent		4		
Soil Type		Reclaimed		Slope Aspect		W		
Reclamation prescription		H ₀ /2°/TSS		% Stoniness to 1m		<2		
LCCS Classification		3		Drainage Class	Well			
CSSC Classification		n/a		Effective Rooting Depth (cm)		40		
Dominant tree species		Aw Sw		Compaction		slight		
Soil Profile Description								
Horizon			TS		US		LS	
Depth			0-13		13-32		32+	
Color			10YR2/2		7.5YR4/2		10YR5/3	
Moisture			d		d		d	
Texture			PM		SCL		LS	
Structure	Primary	Grade	weak		strong		single grain	
		Size	fine		med-coarse			
		Type	granular		ab			
		Consistence	friable		v.firm			
	Secondary	Grade	-		-		-	
		Size	-		-		-	
		Type	-		-		-	
		Consistence	-		-		-	
Boundary	Sharpness		clear		-		-	
	Form		abrupt		-		-	
Mottles	Abundance		-		common		-	
	Size		-		fine		-	
	Distinctness		-		distinct		-	
	Color		-		7.5YR5/6		-	
Effervescence (10%)			x		weak		x	
Rooting at depth			0-10		10-30		-	
Rooting	Abundance	Very fine	abundant		plentiful		-	
		Fine	-		-		-	
		Medium	-		-		-	
		Coarse	plentiful		-		-	
	Orientation	Very fine	vertical		vertical		-	
		Fine	-		-		-	
		Medium	-		-		-	
		Coarse	oblique		-		-	
	Distribution	Very fine	I/E		I/E(dominantly E)		-	
		Fine	-		-		-	
		Medium	-		-		-	
		Coarse	I/E		-		-	

APPENDIX E. VEGETATION DATA

Table E-1. Species list of plants found in natural sites.

CODE	Scientific Name	Common Name
ABIBALS	<i>Abies balsamea</i>	Balsam fir
ACHMILL	<i>Achillea millefolium</i>	Common yarrow
ALNCRIS	<i>Alnus crispa</i>	Green alder
AMEALNI	<i>Amelanchier alnifolia</i>	Saskatoon
ANEPATE	<i>Anemone patens</i>	Prairie crocus
ARANUDI	<i>Aralia nudicaulis</i>	Wild sarsaparilla
ARCUVAU	<i>Arctostaphylos uva-ursi</i>	Kinnikinnick
ASTSPP.	<i>Aster spp.</i>	Aster
BETPAPY	<i>Betula papyrifera</i>	White birch
CAMROTU	<i>Campanula rotundifolia</i>	Common harebell
CARSPP.	<i>Carex spp.</i>	Sedge
CLASTEL	<i>Cladina stellaris</i>	Northern reindeer lichen
COMUMBE	<i>Comandra umbellata</i>	Bastard toadflax
CORCANA	<i>Cornus canadensis</i>	Bunchberry
CORCORN	<i>Corylus cornuta</i>	Beaked hazelnut
CORSTOL	<i>Cornus stolonifera</i>	Red-osier dogwood
DICACUT	<i>Dicranum acutifolium</i>	Cusion moss
DISTRAC	<i>Disporum trachycarpum</i>	Fairy bells
ELYNNO	<i>Elymus innovatus</i>	Hairy wild rye
EPIANGU	<i>Epilobium angustifolium</i>	Fireweed
EQUARVE	<i>Equisetum arvense</i>	Common horsetail
FRAVIRG	<i>Fragaria virginiana</i>	Wild strawberry
GALBORE	<i>Galium boreale</i>	Northern bedstraw
GALTRIF	<i>Galium triflorum</i>	Sweet-scented bedstraw
HYLSPLE	<i>Hylocomium splendens</i>	Stair-step moss
LATOCHR	<i>Lathyrus ochroleucus</i>	Creamy peavine
LATVENO	<i>Lathyrus venosus</i>	Purple peavine
LEDGROE	<i>Ledum groenlandicum</i>	Common labrador tea
LINBORE	<i>Linnaea borealis</i>	Twinflower
LONINVO	<i>Lonicera involucrata</i>	Bracted honeysuckle
LYCANNO	<i>Lycopodium annotinum</i>	Stiff club-moss
MAICANA	<i>Maianthemum canadense</i>	Wild lily-of-the-valley
MELOFFI	<i>Melilotus officinalis</i>	Yellow sweet clover
MERPANI	<i>Mertensia paniculata</i>	Tall Lungwort
PELAPHT	<i>Peltigera aphthosa</i>	Studded leather lichen
PETPALM	<i>Petasites palmatus</i>	Palmate-leaved coltsfoot
PICGLAU	<i>Picea glauca</i>	White spruce
PINBANK	<i>Pinus banksiana</i>	Jack pine
PLESCHR	<i>Pleurozium schreberi</i>	Big red stem or Scherber's moss
POPBALS	<i>Populus balsamifera</i>	Balsam poplar
POPTREM	<i>Populus tremuloides</i>	Aspen poplar
PRUPENS	<i>Prunus pensylvanica</i>	Pin cherry
PTICRIS	<i>Ptilium crista-castrensis</i>	Knight's plume
PYRASAR	<i>Pyrola asarifolia</i>	Common pink wintergreen

PYRSECU	<i>Pyrola secunda</i>	One-sided wintergreen
RIBOXYA	<i>Ribes oxycanthoides</i>	Northern gooseberry
ROSACIC	<i>Rosa acicularis</i>	Prickly rose
RUBCHAM	<i>Rubus chamaemorus</i>	Cloudberry
RUBIDEA	<i>Rubus idaeus</i>	Wild red raspberry
RUBPUBE	<i>Rubus pubescens</i>	Dewberry
SALSPP.	<i>Salix</i> spp.	Willow
SHECANA	<i>Sheperdia canadensis</i>	Canada buffaloberry
SMISTEL	<i>Smilacina stellata</i>	Star-flowered false Solomon's-seal
STRAMPL	<i>Streptopus amplexifolius</i>	Twisted stalk
TRIBORE	<i>Trientalis borealis</i>	Northern starflower
VACMYRT	<i>Vaccinium myrtilloides</i>	Velet-leaved blueberry
VIBOPUL	<i>Viburnum opulus</i>	High bush cranberry
VIORENI	<i>Viola renifolia</i>	Kidney-leaved violet

Table E-2. Species present in natural sites.

Species	Natural sites																						
	Coarse											Fine											
	AUD 2	AUD 3	AUD 4	PSP 161	PSP 163	PSP 166	PSP 171	PSP 197	SV 10	SV 2	Prop	PSP 141	PSP 145	PSP 149	PSP 164	PSP 165	PSP 173	PSP 196	PSP 199	SV 4	SV 6	Prop	
ABIBALS	•	•				•				•	4/10				•	•	•	•	•			5/10	
ALNCRIS		•	•					•			3/10			•				•	•	•		4/10	
AMEALNI		•							•	•	3/10	•	•								•	3/10	
ANEPATE							•		•		2/10											0	
ARANUDI		•	•			•		•		•	5/10											0	
ARCUVAU	•	•	•	•	•	•	•		•	•	9/10						•		•			2/10	
ASTSPP.									•		1/10							•		•		0	
BETPAPY								•		•	2/10				•				•			2/10	
CAMROTU									•		1/10											0	
CARSPP.	•										1/10											0	
CLASTEL	•		•	•	•		•		•		6/10											0	
COMUMBE		•			•			•		•	4/10										•	1/10	
CORCANA	•	•			•	•		•		•	6/10	•	•	•	•	•	•	•	•	•	•	1	
CORCORN											0				•			•				2/10	
CORSTOL											0									•		1/10	
DICACUT							•				1/10											0	
DISTRAC											0				•							1/10	
ELYINNO				•							1/10											0	
EPIANGU				•		•		•	•	•	5/10	•	•	•	•	•	•	•	•	•	•	1	
EQUARVE										•	1/10		•	•				•	•	•		5/10	
FRAVIRG											0	•										1/10	
GALBORE	•	•			•	•			•	•	6/10	•	•	•		•	•	•	•	•	•	9/10	
GALTRIF			•	•							2/10	•						•		•		3/10	
HYLSPLE		•				•		•		•	4/10	•	•	•		•	•	•	•			7/10	
LATOCHR											0						•					1/10	
LATVENO				•		•		•			3/10	•	•	•	•				•	•		6/10	
LEDGROE	•									•	2/10		•			•	•	•			•	5/10	
LINBORE		•		•	•	•		•		•	6/10	•	•	•	•	•	•	•	•	•		9/10	
LONINVO											0								•			1/10	
LYCANNO		•	•	•				•			4/10					•		•				2/10	
MAICANA		•	•	•	•	•	•	•	•	•	9/10	•	•	•	•	•	•	•	•	•		9/10	
MERPANI			•								1/10											0	
PELAPHT								•			1/10					•						1/10	
PETPALM											0	•	•	•		•	•		•	•	•	8/10	
PICGLAU						•		•		•	3/10	•	•		•	•	•			•	•	7/10	
PINBANK	•	•	•	•	•		•		•		7/10											0	
PLESCHR	•	•						•			3/10		•	•	•	•	•					5/10	
POPBALS											0								•	•	•	3/10	
POPTREM	•	•	•		•	•	•	•	•	•	9/10	•	•	•	•	•	•	•		•	•	9/10	

Species	Natural sites																						
	Coarse											Fine											
	AUD 2	AUD 3	AUD 4	PSP 161	PSP 163	PSP 166	PSP 171	PSP 197	SV 10	SV 2	Prop	PSP 141	PSP 145	PSP 149	PSP 164	PSP 165	PSP 173	PSP 196	PSP 199	SV 4	SV 6	Prop	
PRUPENS								■		1/10												0	
PTICRIS		•						•		2/10												0	
PYRASAR										0		•	•					•	•			4/10	
PYRSECU	•					•				2/10	•											1/10	
RIBOXYA										0								•		•		2/10	
ROSACIC	•	•	•	•		•	•	•	•	8/10	•	•	•	•	•	•	•	•	•	•	•	1	
RUBCHAM										0								•				1/10	
RUBIDEA										0		•					•	•				3/10	
RUBPUBE										0	•	•	•	•	•	•	•	•	•	•	•	1	
SALSPP.										0										•		1/10	
SHECANA	•	•		•		•				4/10	•	•	•				•			•	•	6/10	
SMISTEL		•								1/10												0	
STRAMPL										0	•											1/10	
TRIBORE	•	•				•				3/10							•		•			2/10	
VACMYRT	•	•	•	•	•		•	•	•	9/10							•	•			•	3/10	
VIBOPUL						•				1/10	•	•	•	•	•	•	•	•	•	•	•	1	
VIORENI										0	•	•	•	•	•				•	•		6/10	
Grass	•	•	•		•	•		•	•	8/10	•	•	•	•	•	•	•	•	•	•	•	9/10	
Total •	16	22	13	13	11	18	9	20	13	19	-	21	22	19	17	20	21	22	22	22	15	-	

Table E-3. Volume estimation paramenters (basal diamenter, diameter breast height and height), stand age and site index for natural sites.

Site	Species	DB (cm)	DBH (cm)	Height (m)	Age	SI ^ε (50 years)	Source
AUD 2	Pj	27.7	22.4	16.1			
	Pj	22.7	18.4	17.1			
	Pj	29.7	24.3	19.0	54	19	a
AUD 3	Aw	18.7	14.1	9.8	27	16	a
	Aw	14.4	11.7	14.3			
	Fb	10.8	10.0	10.2			
	Fb	19.9	16.4	12.9	36	n/a	n/a
	Pj	74.6	62.8	26.2	141	17	a
AUD 4	Aw	12.9	10.9	9.0			
	Aw	14.4	12.7	10.9	36	14	a
	Pj	19.3	14.2	11.2			
	Pj	25.4	19.8	15.3			
	Pj	25.7	21.8	15.6	33	20	a
PSP 141	Aw	14.3	12.5	17.1			
	Aw	20.9	17.4	20.5			
	Aw	25.6	21.8	20.7			
	Aw	22.3	19.8	21.6			
	Aw	23.1	20.2	22.1			
	Aw	20.0	17.3	22.4			
	Aw	23.9	20.2	23.6			
	Aw	26.9	23.6	24.6			
	Aw	30.1	27.8	26.4	60	24	a
PSP 145	Aw	27.2	24.4	20.4			
	Aw	47.9	40.7	24.5	†	†	b
	Sw	17.9	15.8	11.2			
	Sw	38.8	36.7	16.3	-	15	b
	Sw	22.6	19.6	17.0			
PSP 149	Aw	13.7	11.6	14.1			
	Aw	14.6	12.4	15.4			
	Aw	12.9	10.5	16.1			
	Aw	12.9	11.1	16.2			
	Aw	15.7	12.9	17.9			
	Aw	16.8	12.8	18.8			
	Aw	24.8	20.1	20.4	40	23	a
	Aw	22.0	18.1	20.4			
	Aw	18.4	14.7	21.5			
PSP 161	Pj	28.1	21.8	15.1			
	Pj	28.3	22.6	16.7			
	Pj	29.8	23.1	16.9	57	15	a
PSP 163	Aw	9.9	8.0	9.1			
	Aw	15.8	11.3	10.2			
	Aw	14.9	10.9	10.2			
	Aw	15.7	10.0	10.4			

Site	Species	DB (cm)	DBH (cm)	Height (m)	Age	SI ^ε (50 years)	Source
	Aw	16.3	14.0	11.3			
	Aw	24.0	20.6	14.0	45	16	a
	Pj	32.0	27.3	12.5			
	Pj	36.7	31.1	13.0	49	13	a
PSP 164	Aw	22.6	18.7	14.5			
	Aw	29.1	23.5	18.3			
	Aw	23.6	19.8	20.9			
	Aw	21.6	17.5	20.9			
	Aw	43.4	31.9	23.7	55	23	a
	Aw	24.2	20.2	24.3			
	Bw	12.7	10.7	18.2	29	n/a	n/a
	Fb	11.3	10.4	9.3	31		
	Sw	24.7	19.9	19.4			
	Sw	33.4	27.4	22.4			
	Sw	33.2	28.7	26.8	84	19	a
PSP 165	Aw	4.6	3.6	10.0			
	Aw	12.5	11.3	15.6			
	Aw	19.4	16.3	16.1			
	Aw	28.7	21.0	18.3			
	Aw	29.7	23.6	18.9			
	Aw	28.7	21.7	19.1			
	Aw	20.1	17.4	19.5			
	Aw	29.2	22.8	21.3			
	Aw	25.5	22.2	21.5			
	Aw	25.3	21.4	22.5			
	Aw	25.7	20.6	22.8			
	Aw	28.1	20.9	23.4			
	Aw	24.5	21.0	23.6			
	Aw	30.7	24.9	24.9			
	Aw	31.1	25.8	25.2			
	Aw	27.4	23.7	28.2	58	27	a
	Fb	4.8	3.7	6.0			
	Fb	5.8	3.9	6.9			
	Fb	7.2	5.6	8.7			
	Sw	3.7	2.1	2.1			
	Sw	4.0	2.4	2.3			
	Sw	3.1	1.6	3.1			
	Sw	13.8	9.3	6.6			
	Sw	18.3	13.8	7.0	48	7	a
	Sw	8.4	6.4	7.6			
	Sw	13.3	9.2	9.4			
	Sw	17.2	12.3	11.3			
	Sw	17.6	12.6	16.1			
PSP 166	Aw	35.9	26.1	16.2			
	Aw	27.2	23.4	16.4			

Site	Species	DB (cm)	DBH (cm)	Height (m)	Age	SI ⁶ (50 years)	Source
	Aw	29.0	22.3	16.5		64	18
	Aw	21.2	17.5	17.3			
	Aw	25.0	22.1	19.3			
	Aw	32.3	26.4	21.8	29		a
	Fb	12.4	11.3	11.8			
	Sw	8.8	6.2	6.4			
	Sw	9.1	7.4	6.7	47	15	a
	Sw	17.1	14.5	14.1			
PSP 171	Pj	26.9	18.1	12.0			
	Pj	16.4	14.7	12.1			
	Pj	18.7	14.3	13.0			
	Pj	25.1	22.3	15.2			
	Pj	27.0	21.7	15.7			
	Pj	22.4	18.3	15.7			
	Pj	30.2	23.4	15.8			
	Pj	32.7	25.9	16.0			
PSP 173	Aw	21.3	18.6	17.7			
	Aw	18.3	16.0	19.7			
	Aw	33.4	29.1	20.0			
	Aw	28.3	26.6	22.2			
	Aw	30.7	26.5	23.6			
	Aw	32.7	31.9	24.0			
	Sw	13.0	10.3	8.5	93	17	a
	Sw	32.8	27.8	22.4			
	Sw	28.7	24.7	24.6			
PSP 196	Aw	16.2	12.7	16.3			
	Aw	26.7	21.8	17.6			
	Aw	33.6	24.9	20.4			
PSP 197	Aw	23.9	21.2	19.0			
	Aw	23.9	19.6	20.0			
	Aw	23.6	19.3	22.9			
	Aw	29.4	19.4	23.0			
	Aw	33.4	25.6	25.7			
PSP 199	Aw	-	-	-	-	20	b
	Bw	22.1	18.6	10.5		19	b
	Bw	20.5	17.3	11.6			
	Bw	16.4	13.7	11.6			
	Bw	17.4	15.4	13.7			
	Bw	19.7	15.8	14.9			
	Bw	20.3	17.6	17.3			
	Pb	18.3	16.1	20.1			
SV 10	Pj	15.4	12.1	12.2			
	Pj	13.4	12.6	13.3			
	Pj	14.2	12.5	13.4			
	Pj	16.4	13.6	14.3			

Site	Species	DB (cm)	DBH (cm)	Height (m)	Age	SI ^ε (50 years)	Source
	Pj	17.9	14.8	14.4	38	18	a
	Pj	19.0	15.5	15.4			
	Pj	24.6	17.9	15.7			
	Pj	21.8	17.0	16.3			
SV 2	Aw	16.4	12.7	10.5	25	17	a
	Sw	44.2	34.7	21.5	55	23	a
	Sw	54.6	45.7	24.6			
SV 4	Aw	14.1	11.7	17.0	72	22	a
	Aw	16.3	12.9	20.6			
	Aw	19.3	15.8	20.8			
	Aw	19.6	16.7	21.1			
	Aw	19.5	16.4	22.0			
	Aw	21.4	17.0	23.3			
	Aw	24.1	20.2	24.3			
	Aw	18.7	15.7	24.3			
	Aw	16.9	14.7	24.7			
	Aw	21.5	16.9	24.7			
	Aw	20.3	15.5	25.2			
	Aw	27.4	23.5	26.5			
	Aw	29.6	22.7	29.9			
	Aw	24.7	21.7	30.1			
	Aw	28.7	22.2	31.4			
	Aw	25.7	22.3	32.1			
	Pb	14.5	13.2	4.5	57	<6	a
SV 6	Aw	16.4	14.1	14.2	†	†	b
	Aw	17.7	13.7	14.6			
	Aw	16.4	12.3	15.7			
	Aw	18.2	13.4	18.6			
	Aw	20.1	16.2	20.4			
	Aw	21.6	15.9	21.2			
	Aw	14.3	11.5	21.6			
	Pb	15.8	12.6	14.8	62	16	a
	Pb	44.0	30.8	18.6			
	Sw	12.9	10.3	7.7	-	15	b
	Sw	15.3	13.5	10.2			
	Sw	12.6	10.1	11.4			
	Sw	16.6	13.2	12.5			
	Sw	18.7	11.9	12.9			
	Sw	14.9	11.9	13.3			
	Sw	13.2	10.8	13.9			
	Sw	13.9	11.3	14.9			
	Sw	19.2	13.9	17.9			
	Sw	19.9	14.7	17.9			
	Sw	19.8	17.4	18.3			
	Sw	18.8	14.6	19.8			

a = current study, age applies to the tree in that row

b = Soil and vegetation ongoing monitoring program, provided by Paragon Soil and Environmental Consultants, applies to the species, not a specific tree

† = unable to core

£ = Site index at 50 years (Huang 1997; Chapter 4)

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